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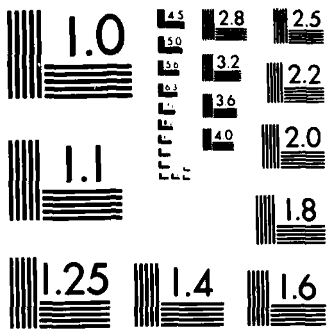

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Program Engineering
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Washington, D.C. 20591

Field Validation of Statistically Based Acceptance Plan for Bituminous Airport Pavements

Volume 1—Correlation Analysis of Marshall Properties of Laboratory-Compacted Specimens

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16. Abstract
The laboratory phase of a three phase research effort conducted to field validate a multiple price adjustment system for bituminous airport pavements using the Marshall properties, stability, flow and air voids, is presented. The purpose of the laboratory phase was to identify whether correlations exist among the Marshall properties within individual tests. To consider the use of these properties in a multiple price adjustment system, it was first necessary to identify these correlations.

The experimental design consisted of 4 different aggregate gradations and 6 different asphalt contents for a total of 24 combinations. A total of 12 replicates were tested for each combination for a total of 288 Marshall test specimens. A number of statistical analyses were conducted on the laboratory test results. An analysis of variance was conducted to determine whether time, i.e., order of testing, had an effect on the results. Correlation coefficients among the Marshall properties, i.e., stability with flow, stability with air voids and flow with air voids, were calculated for each of the 24 combinations.

The results of the analysis indicate correlations that are consistent enough to violate an assumption of statistical independence among the properties. The results indicate that the effect of correlations among the properties should be taken into consideration in developing a multiple price adjustment approach based on the Marshall properties.

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PREFACE

This report presents the findings of a research project entitled "Field Validation of Statistically Based Acceptance Plan for Bituminous Airport Pavements", Report No. DOT/FAA/PM-84/12, that was conducted to investigate the use of Marshall properties for acceptance purposes. The results of the research effort are presented in the series of reports listed below:

Burati, J.L., Brantley, G.D. and Morgan, F.W., "Correlation Analysis of Marshall Properties of Laboratory Compacted Specimens," Final Report, Volume 1, Federal Aviation Administration, May, 1984.

Burati, J.L., Seward, J.D. and Busching, H.W., "Statistical Analysis of Marshall Properties of Plant Produced Bituminous Materials," Final Report, Volume 2, Federal Aviation Administration, May, 1984.

Burati, J.L. and Seward, J.D., "Statistical Analysis of Three Methods for Determining Maximum Specific Gravity of Bituminous Concrete Mixtures," Final Report, Volume 3, Federal Aviation Administration, May, 1984.

Nnaji, S., Burati, J.L. and Tarakji, M.G., "Computer Simulation of Multiple Acceptance Criteria," Final Report, Volume 4, Federal Aviation Administration, August, 1984.

Burati, J.L., Busching, H.W. and Nnaji, S., "Field Validation of Statistically Based Acceptance Plan for Bituminous Airport Pavements — Summary of Validation Studies," Final Report, Volume 5, Federal Aviation Administration, September, 1984.

The application of multiple price adjustments is significantly more involved than the case when only one property, e.g., density, is considered. Since the Marshall properties (i.e., stability, flow and air voids) are physically related, they can be expected to be statistically correlated. If this is truly the case, then it may not be sufficient to treat each of the three properties individually. It is necessary to determine whether correlations exist among these properties, and whether such correlations should be considered when developing acceptance plans.

The objectives of the research described in the reports listed above include:

1. Review current methods of determining maximum specific gravity for use in air voids calculations for possible incorporation into the FAA Eastern Region P-401 specification,

2. Investigate the use of price adjustments when more than one characteristic is being used for acceptance purposes and recommend to the FAA potential procedures for dealing with multiple price adjustments,

3. Develop the procedures necessary to evaluate the performance of multiple properties acceptance plans,

4. Implement proposed Marshall properties acceptance plans on demonstration projects under actual field conditions, and

5. Attempt to correlate values of asphalt content and aggregate gradation with those from Marshall tests to determine whether or not correlations exist among these properties.

This report, Volume 1, presents the findings of a laboratory analysis to determine whether correlations exist among the Marshall properties. How correlations can be considered in the development of price adjustment systems is presented in the subsequent volumes.

CHAPTER I

INTRODUCTION

The Federal Aviation Administration (FAA) incorporated statistical concepts into its bituminous surface course (Item P-401) acceptance plan in 1978 by using the mean and the range of mat density tests to determine acceptability. In 1980, as a result of an FAA-sponsored research effort (1), the mean and standard deviation for mat density tests were incorporated into a statistically based price adjustment system. The final report of the research effort indicated that there were not sufficient data available to warrant the implementation of a multiple characteristic acceptance plan that included price adjustments for Marshall properties as well as mat density.

The final research report (1) recommended further study to determine the feasibility of applying multiple price adjustments using the Marshall properties. These properties are physically related (i.e., determined from a single test) and therefore can be expected to be statistically correlated. Because of this, it is necessary to identify any correlatons existing among these properties before attempting to apply multiple price adjustment factors. If a high correlation does exist among 2 or more of the properties, then it can be argued that the correlated properties are, in fact, measuring the same characteristic of the mix and the price adjustment system should incorporate only 1 of these properties to avoid penalizing the contractor twice for the same deficiency.

Basis For Study

The current research is a direct result of the recommendations made in the final report (1) of the initial research effort. The recommendations proposed a 3-phase research project. The ultimate goal of the recommendations was to obtain a multiple price adjustment system using the Marshall properties for the FAA Eastern Region to apply on bituminous paving projects. The 3 phases of research proposed were the laboratory phase, the field phase, and the computer simulation phase. This report presents the results of the laboratory phase of the research that developed as a result of that proposal

To establish multiple price adjustment factors, it is necessary to determine whether any correlations exist among the Marshall properties as a result of their physical relationship. The purpose of the laboratory phase of the research is to identify whether such correlations exist and to estimate their magnitude.

Research Objective

The objective of the research is to determine whether significant correlations exist among the Marshall properties of stability, flow, and air voids. The specific correlations to be considered are stability with flow, stability with air voids, and flow with air voids.

Potential Research Benefits

The results of this research will be used in the investigation of the feasibility of establishing a multiple price adjustment system using Marshall stability, flow, and air voids for the Federal Aviation Administration's Eastern Region. If correlations are found to exist among the properties, multiple price adjustment factors can be established to account for the properties that measure the same characteristic of the mixture. This will prevent the contractor from being penalized twice for the same deficiency. If correlations exist, either some of the tests required by the FAA Eastern Region could possibly be eliminated, or it may be necessary to develop a method of including the correlatons in the acceptance decision.

Literature Review

Although the Marshall test has been used for more than 40 years, with many research projects on the Marshall properties, no previous research relating to within-test correlations among the properties was found. The correlations existing between each property and ashpalt content are well established, but it appears little is known of the correlations existing between each Marshall property for a given asphalt content and gradation.

CHAPTER II

RESEARCH PROCEDURES

The research effort was divided into 3 principal areas. The initial step was the experimental design. This included defining the range of asphalt cement contents and aggregate gradations to use as well as determining the number of replicates to provide the desired level of confidence. The next step was to procure and perform related tests on the required materials. Once this was accomplished, the mixing and testing of Marshall briquets could begin. The Marshall test method was used rather than other methods of testing because the Marshall parameters (stability, flow, air voids) are used for acceptance purposes by the Federal Aviation Administration.

Experimental Design

The research was designed to identify correlations among the Marshall properties. The goal of the experiment was to determine whether the levels of correlation among the Marshall properties vary with asphalt content and aggregate gradation. Other variables were held as constant as possible to prevent them from influencing the Marshall test results. Such variables included aggregate quality, asphalt type, temperature (mixing, compaction, and testing), equipment, operators, etc. To determine the effects of asphalt content and aggregate gradation on the correlation analysis, a range of asphalt contents and aggregate gradations was required. It was desired to cover as broad a range of asphalt contents and aggregate gradations as possible.

To determine the appropriate number of asphalt contents and aggregate gradations to use, the standard FAA Eastern Region specifications and the various state versions of the specifications for aggregate gradation and asphalt content for aircraft loads greater than 60,000 pounds and a maximum 3/4-inch stone were compared. Each of the specificatons required the bitumen content to be between 5.0% and 7.5% of the total mix weight. As defined in the Eastern Region Laboratory Procedures Manual (ERLPM) (9), the laboratory procedures for developing the job mix formula for a paving project require the aggregate gradations to be tested at 0.5% asphalt content increments. Since it was desired to span as broad a range of asphalt contents as possible, based on these specifications and the ERLPM, 6 asphalt contents (5.0%, 5.5%, 6.0%, 6.5%, 7.0%, 7.5%) were selected for testing.

The aggregate gradation limits specified by Pennsylvania, Virginia, New York, and the Eastern Region standard specification are presented in Table I and Figures 1-4, respectively. The center lines in the figures are the midpoints of each specification band. After comparing the specifications, several groupings could be made. The specification limits for the Virginia, New York, and Eastern Region were similar and, therefore, considered the same. It was also concluded that the midpoint

Table I. Summary of Aggregate Gradation Limits Considered

Sieve Size	Percent Passing			
	Pennsylviania	Virginia	New York	Regional 2A
3/4 in.	100	100	100	100
1/2 in.	77-96	82-96	82-96	82-96
3/8 in.	68-89	75-89	-	75-89
1/4 in.	-	-	65-79	-
No.4	48-73	59-73	-	59-73
1/8 in.	-	-	51-65	-
No.8	34-60	46-60	-	46-60
No.16	23-48	34-48	-	34-48
No.20	-	-	29-43	-
No.30	16-38	24-38	-	24-38
No.40	-	-	20-33	-
No.50	10-27	15-27	-	15-27
No.80	-	-	10-20	-
No.100	6-18	8-18	-	8-18
No.200	3-6	3-6	3-6	3-6

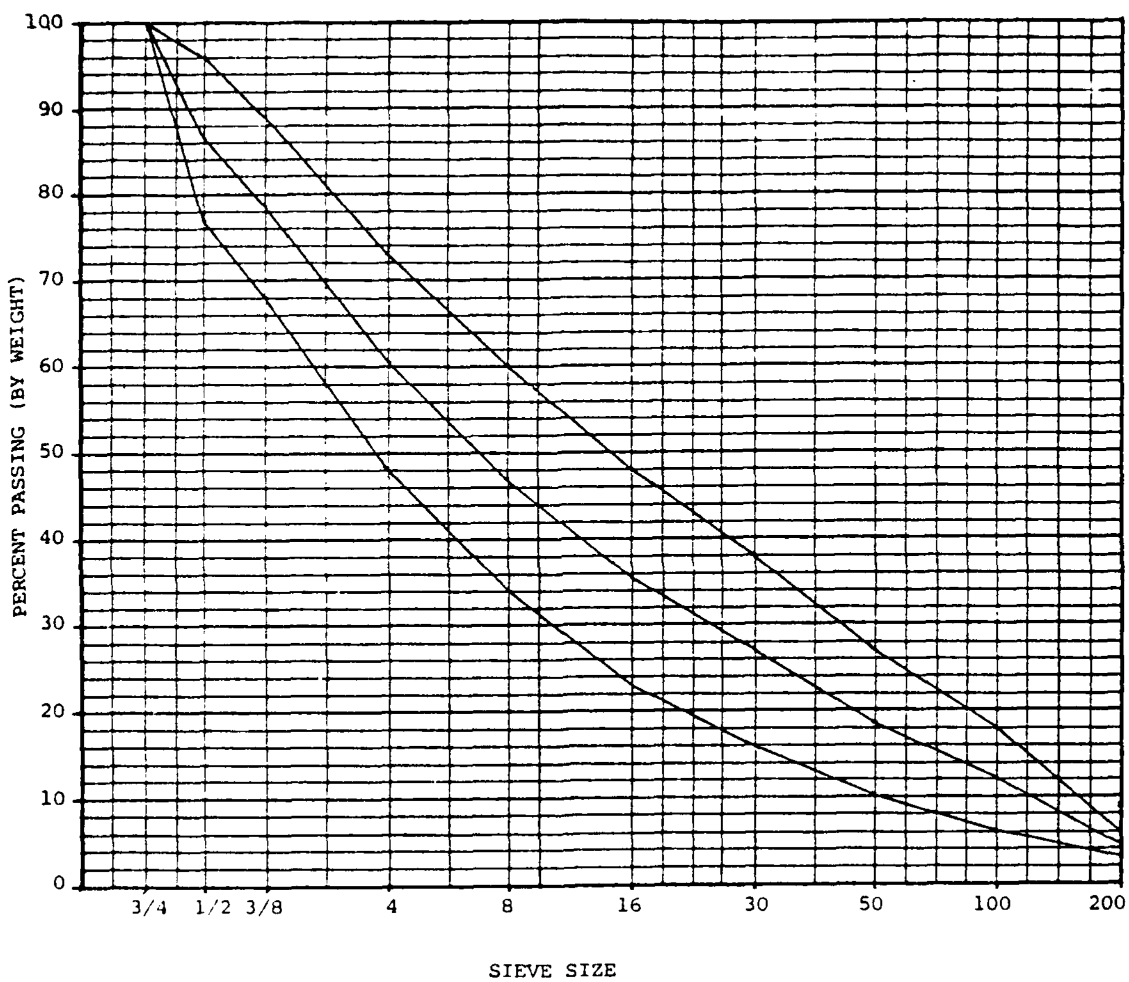

Figure 1. Aggregate Gradation Limits from the Pennsylvania Specifications for loads ≥ 60,000 lbs. or tire pressures ≥ 100 psi. (Center line is midpoint of specification limits.)

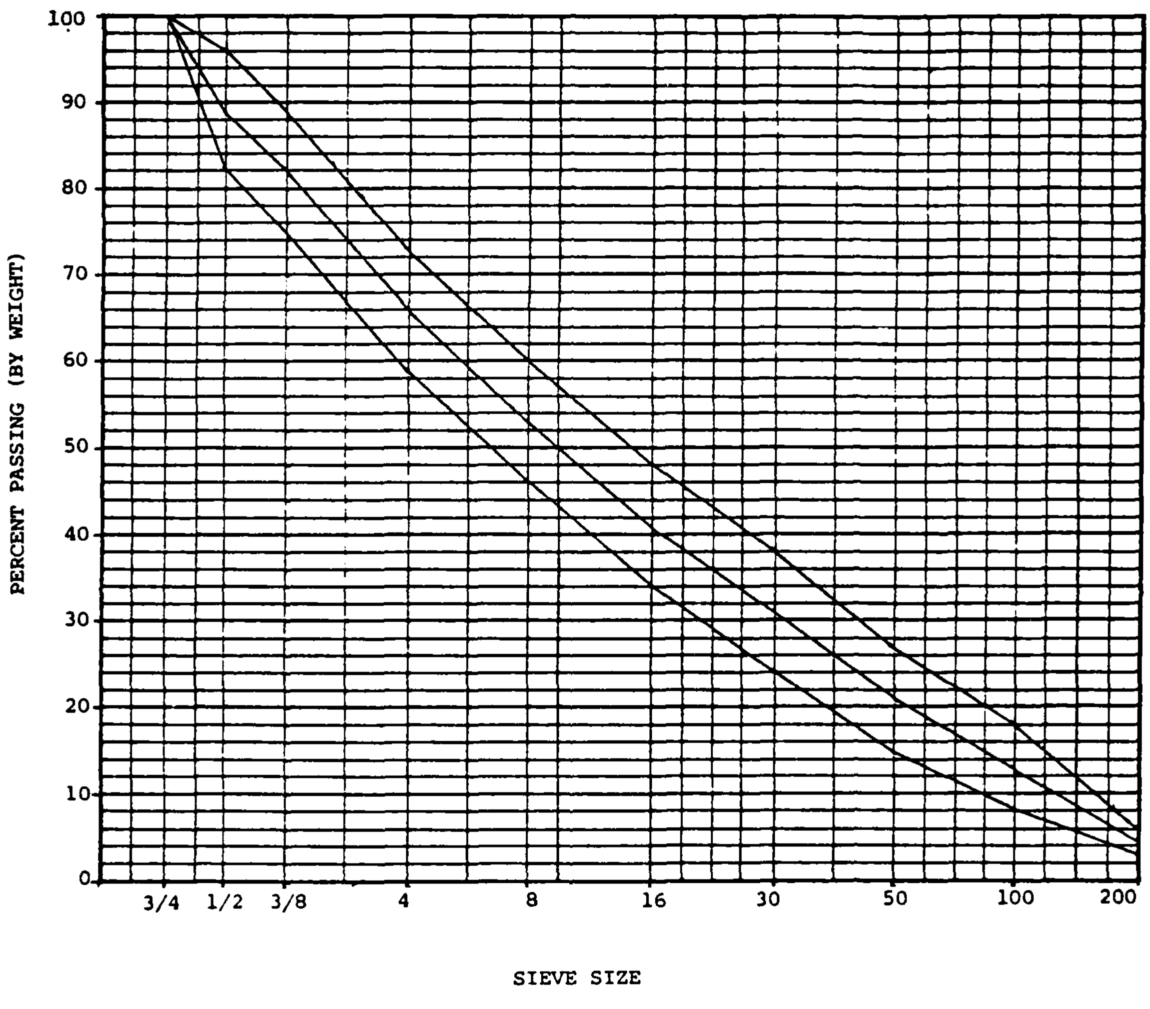

Figure 2. Aggregate Gradation Limits from the Virginia Specifications. for loads ≥ 60,000 lbs. or tire pressures ≥ 100 psi. (Center line is midpoint of specification limits.)

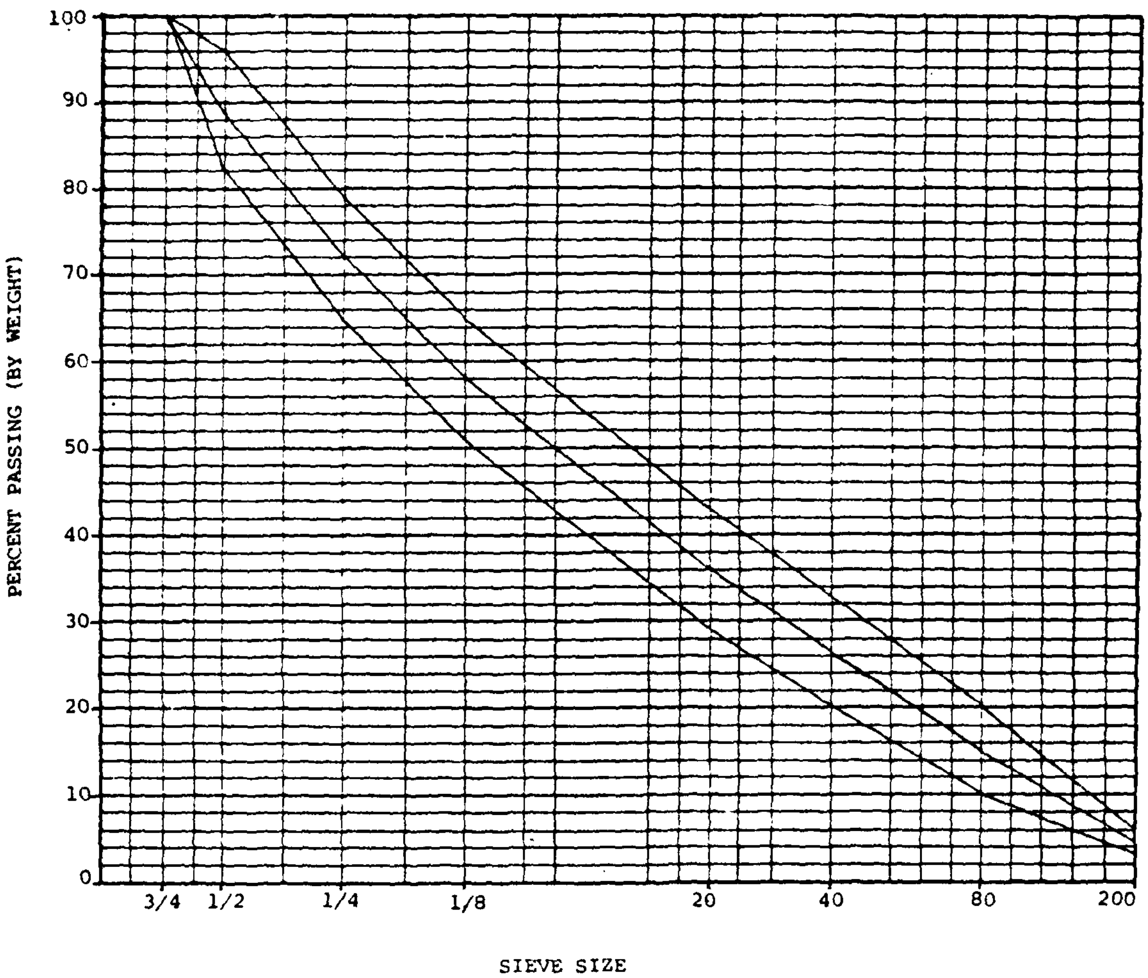

Figure 3. Aggregate Gradation Limits from the New York Specifications for loads ≥ 60,000 lbs. or tire pressures ≥ 100 psi. (Center line is midpoint of specification limits.)

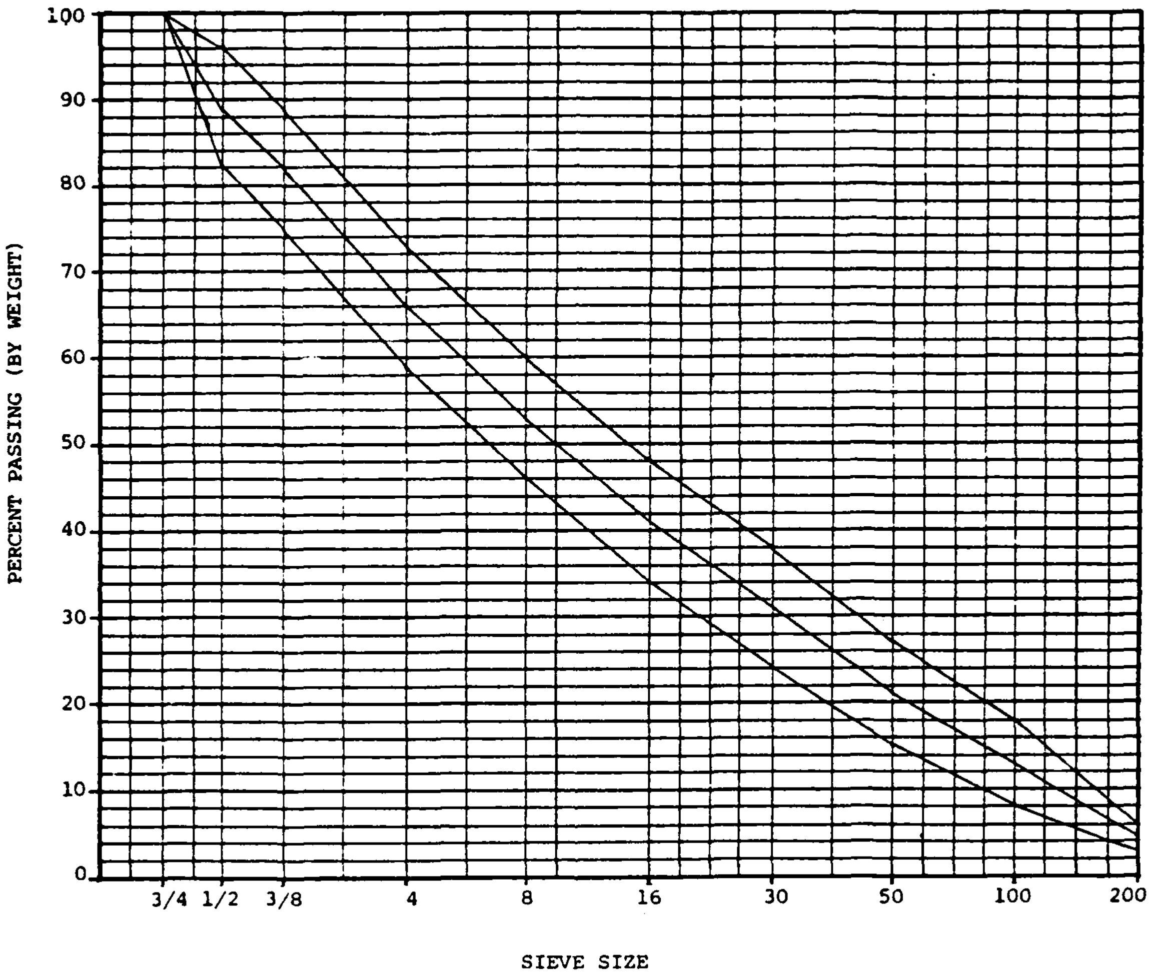

Figure 4. Regional Gradation Limits for loads ≥ 60,000 lbs. or tire pressures ≥ 100 psi. (Center line is midpoint of specification limits.)

and upper specification limit for the Pennsylvania specifications and the lower and upper specificaton limits for the Regional, respectively, were close enough to be considered the same. After making these groupings, 4 distinct aggregate gradations were established that spanned the entire allowable limits established by the Virginia, Pennsylvania, New York, and Eastern Region lower, midpoint, and upper specification limits. It was concluded that the lower Pennsylvania specification was not very realistic because of its extremely low gradation band in comparison with the other specifications and it was therefore deleted.

Based on experience obtained from mixing and testing several practice Marshall briquets, it was decided that approximately 20 to 25 briquets could be mixed on 1 day and tested the next without rushing the process. By mixing and testing all combinations of asphalt content and aggregate gradation at the same time, the effects due to time should be restricted to variatons between each replicate and not within each replicate. With this in mind, and the fact that 6 asphalt contents were desired, 4 gradations were selected. This would provide a total of 24 combinations for each replicate. As noted earlier, the aggregate specification limits could be spanned with only 3 gradations with the deletion of the Pennsylvania lower specification limits. The job mix formula (JMF) gradation used for a Rochester-Monroe County airport paving project in New York was chosen as the fourth gradation. The Rochester-Monroe project was 1 of 5 airport paving projects studied in the field phase of the 3-phase FAA research project. The 4 gradations are summarized in Table II and plotted in Figure 5. The Upper, Midpoint, Lower, and JMF bands in the plot represent the FAA Upper, FAA Midpoint, FAA Lower, and the Rochester job mix formula gradation bands, respectively.

After the aggregate gradations and asphalt contents were established, the number of replicates for each combination of gradation and asphalt content required to produce the desired level of confidence in the results was determined.

Sample Size Determination

Since it is not possible to determine exactly the correlation coefficient for each asphalt content/aggregate combination, it was desired to determine whether any significant correlations existed among the properties. To determine whether a correlation was present, power curves depicting the probability of detecting a certain magnitude of correlation for a given sample size, or number of replicates, were obtained (11). The power of the test is the probability of rejecting the null hypothesis. If the null hypothesis is not true, then the chance of rejecting the hypothesis should be as large as possible, i.e., a large value is desired for the power. A plot showing the relatonship between power of the test at the 0.1 significance level and the number of replicates is presented in Figure 6.

To determine the relationship between sample size and the power of the test, the null hypothesis was that the true correlation was 0 (Ho: $\rho=0$), and the alternate hypothesis was for a correlation not equal to 0 (Ha: $\rho\neq0$). The power was determined for the cases when the true

Table II. Summary of Aggregate Gradations Chosen for Research Effort

Sieve Size	Percent Passing			
	FAA Regional Lower	FAA Regional Midpoint	FAA Regional Upper	Rochester-Monroe Job-Mix
3/4 in.	100	100	100	100
1/2 in.	82	89	96	98.6
3/8 in.	75	82	89	84.6
No.4	59	66	73	66.5
No.8	46	53	60	55
No.16	34	41	48	42
No.30	24	31	38	31
No.50	15	21	27	20
No.100	8	13	18	8.5
No.200	3	4.5	6	3.8

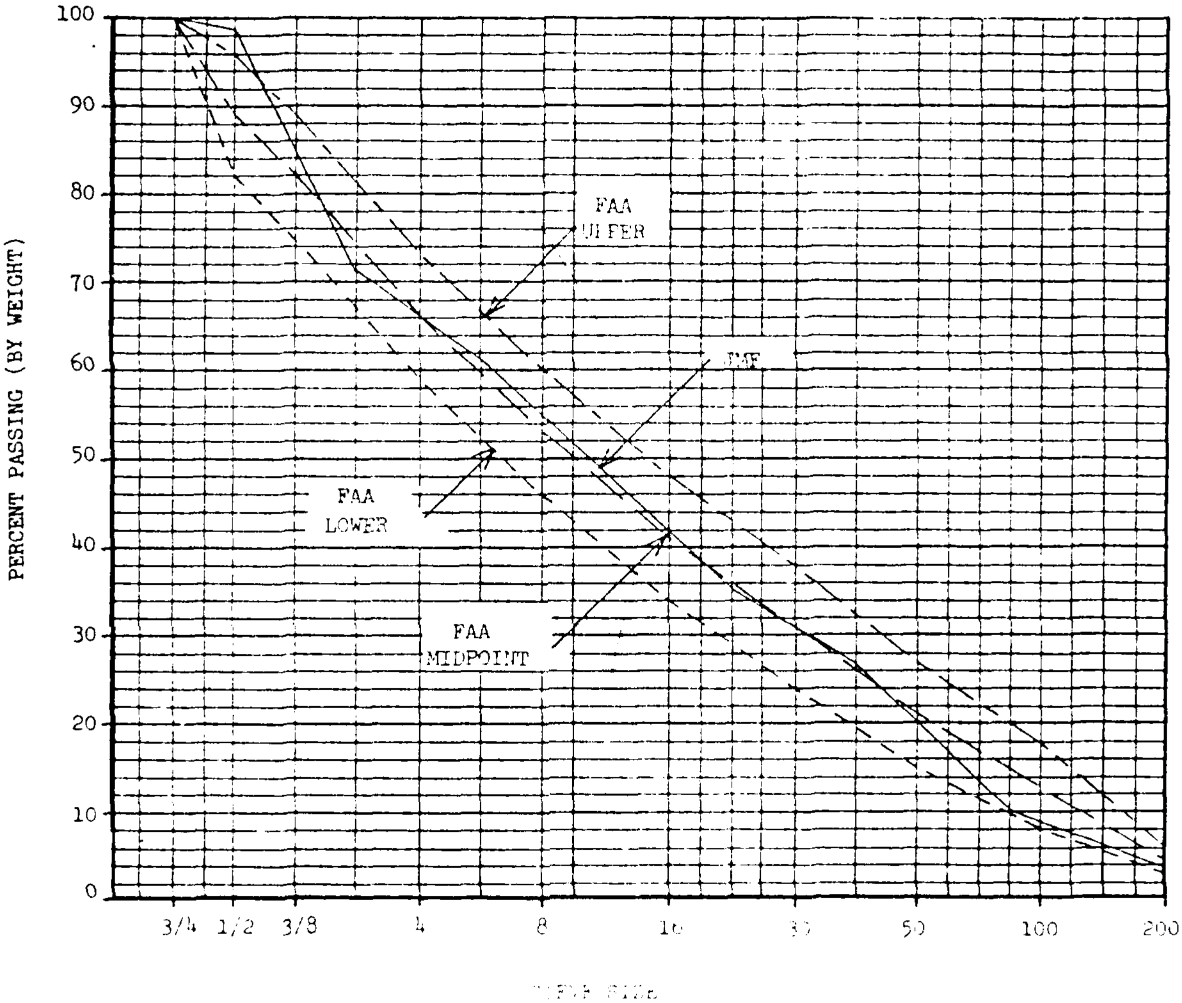

Figure 5. Summary of Aggregate Gradations Chosen for Research Effort

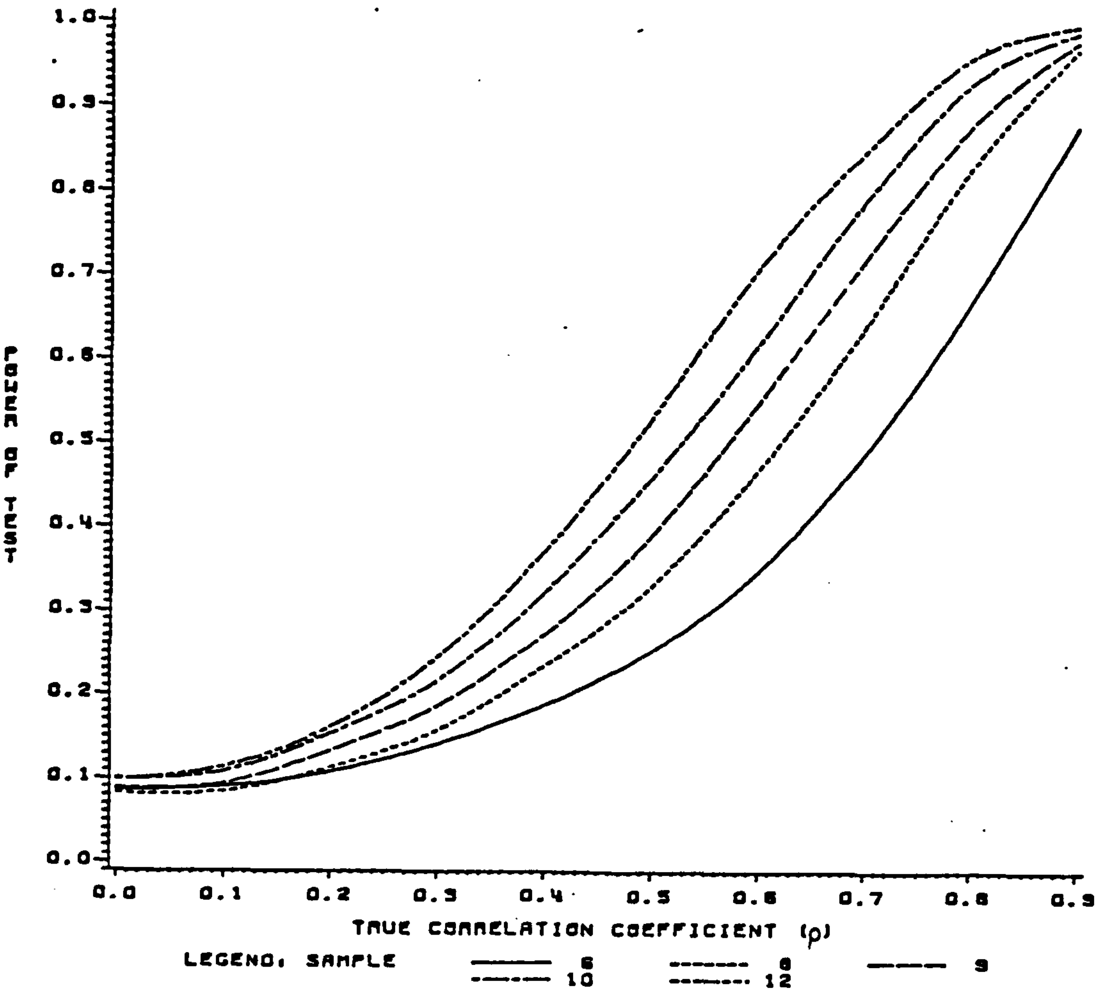

Figure 6. Relationship Between Power for Testing the Null Hypothesis, Ho: $\rho=0$, versus the Alternate Hypothesis, Ha: $\rho\neq0$, and the Number of Replicates for a 0.1 Significance Level.

correlaton coefficient, , was equal to 0.1, 0.2, ... 0.8, 0.9. The true correlation coefficient is represented on the horizontal axis in Figure 6, and the probability of detecting a correlation, i.e., rejecting the null hypothesis that there is not a correlation, is along the vertical axis. Each curve represents a different number of replicates. As would be expected, as the number of replicates increases, the probabilitiy of detecting a correlation also increases.

Considering this, a minimum of 9 replicates were required to provide the level of significance desired. The desirable level of significance was the detection of a very high correlation with a probability near 1.0 and detection of a moderate correlation of 0.5 to 0.6 with a probability about 0.5. If there is a true correlation coefficient of 0.8 or greater among the Marshall properties, then, for 9 replicates, there is approximately a 90% chance of rejecting the null hypothesis that no correlation exists and saying there is some correlation among the properties. For a true correlation coefficient of 0.6, there is approximatly a 55% chance of rejecting the null hypothesis. After practice samples were mixed and tested, a maximum of 12 replicates were possible, given the time and resources available. With 12 replicates, there is approximately a 96% chance of rejecting the hypothesis of no correlation if a true correlation coefficient of 0.8 or greater exists among the properties, and approximately a 71% chance of rejecting the hypothesis of no correlaion if a true correlation coefficient of 0.6 exists among the properties.

Steps Taken to Reduce Testing Variability

Factors influencing the variability of the test results were either eliminated or reduced as much as possible. In addition to the factors described below, others were listed in the experimental design section of this chapter. To reduce the learning curve effect on the laboratory technicians, 96 briquets, or 4 replicates, were mixed and tested as trial runs. The same 3 technicians were used throughout the mixing and testing operations to reduce variations among operators. One was responsible for sieving and weighing the aggregate. The second laboratory technician was responsible for assisting the third during the mixing and compaction processes and was responsible for clean-up. The third technician supervised all laboratory efforts and performed all mixing, testing and briquet weighing.

A random selection process was used to eliminate bias in the order of mixing and testing the briquets. The testing order was the same as the mixing order for each replicate. This order was determined by drawing a slip of paper from a container containing 24 identical slips; 1 for each combination of the 6 asphalt contents and 4 gradations. This process was repeated for each replicate.

Due to the large number of briquets in each replicate, each replicate was mixed on one day and tested the next. By mixing and testing in this order, variations in the results due to time should be confined to differences between the replicates. It is very unlikely that time would cause variations within the replicate from mixing on one day and testing the next. Even if time did have an effect, all of the

replicates should be affected in the same fa.hion.

The same equipment was used throughout the research effort. The Marshall testing machine used (Model 850 manufactured by the Pine Instrument Company) automatically records the stability and flow. The testing machine was checked for proper calibration at the start of each week. A Pine Instrument Company Model PMC4 automatic compactor was aiso used. A dial thermometer was checked for calibration before each mixing day.

Due to the large number of briquets mixed in a single day (24) and the limited supply of Marshall molds (15), 12 briquets were mixed in the morning and 12 in the afternoon. This was required to enable 9 of the molds to cool and be extruded, cleaned, and reheated for the second set of 12 briquets in the afternoon.

A data sheet was developed to record pertinent information. This data sheet is presented in Figure 7. The order for aggregate gradation and percent asphalt content was determined by a random process as described above. The asphalt weight was shown to aid the laboratory technicians when weighing the asphalt cement into the aggregate mixture. To analyze the effect of temperature on the test results and ensure that the various temperatures were within the specification limits, the asphalt, mixing, and compaction temperatures were recorded. The testing temperature was not recorded due to the small variation allowed by the specification limits (140°+/- 1.8°F). The asphalt temperature was the temperature of the asphalt cement before adding it to the aggregate. The mixing temperature was taken as the temperature of the aggregate and asphalt cement combination immediately prior to mixing, and the compaction temperature was the temperature of the mixture immediately before compaction. The thickness of the Marshall briquets was measured to the nearest 1/32-inch and then converted to decimal equivalent. The briquets were weighed the day of testing. The measured stability and flow were recorded from the Marshall test plots. On some plots, the flow formed a plateau at the maximum staility. For these plots, the flow value was determined as illustrated in Figure 8.

Pretesting Preparation

After the experimental design was finalized, the necessary materials were acquired and tests were performed to determine specific aggregate properties. The aggregate and asphalt cement used in the research were materials commonly used in the FAA Eastern Region. The asphalt cement was obtained from West Bank Oil, Inc., Pennsauken, New Jersey. The asphalt cement was AC-20 grade with a penetration value of 79 at 77°F. The absolute viscosity was 1,971 poises at 140°F and the kinematic viscosity was 376 centistokes at 275°F. The aggregate consisted of limestone obtained from the General Crushed Stone Company quarry at Honeoye Falls, New York, and a natural sand from Baugham Materials in West Bloomfield, New York.

A gradation analysis was conducted in accordance with ASTM C-136 on the limestone and natural sand. It was found that adequate quantities of limestone were available to meet the gradations to be used in the

FAA BITUMINOUS CONCRETE TEST DATA

REPLICATE :
DATE OF MIX :
DATE OF TEST:

SP. #	Grada-tion	Asphalt Wgt.	Asphalt Content Percent	TEMPERATURE °F			Thick-ness Inches	WGT------GRAMS			Meas. Stab. lbs	Flow Units of 1/100in
				Asphalt	Mixing	Comp.		In Air	In Water	Sat.Sur Dry		
1												
2												
3												
4												
5												
6												
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Figure 7. Bituminous Concrete Laboratory Test Data Sheet

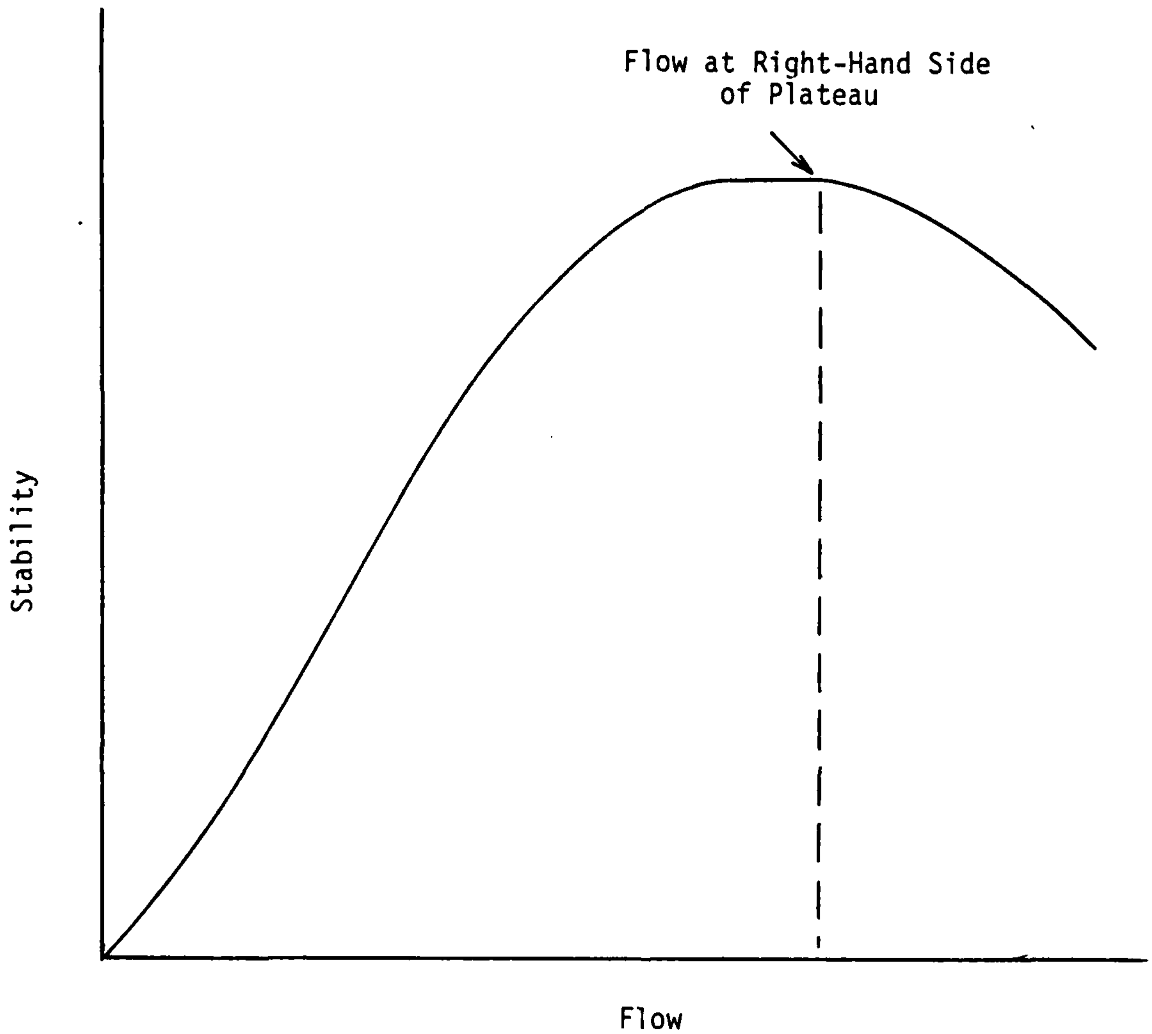


Figure 8. Flow Determination for Plateau Shaped Plots Between Stability and Flow

experiment. It was determined from the gradation analysis that there was sufficient natural sand to supply approximately 15% of the aggregate weight. Due to limitations on the the availability of natural sand in certain sieve ranges, the actual amount of natural sand used was 14.8% by weight of the total aggregate in the mix.

Natural sand was used because the FAA Eastern Region permits the contractor to use natural sand to facilitate field compaction of the dense-graded mix, and this is typical of current practices within the Eastern Region. The primary purpose of the natural sand is to increase the workability of the mix as it is being placed.

Specific gravity and absorption tests were performed after the aggregate was sieved. The tests were run in accordance with ASTM C-128 for fine aggregate and ASTM C-127 for coarse aggregate. The results are shown in Table III along with the specific gravity and absorption values provided by the material suppliers' laboratories. The values for both tests were slightly different. Confidence in the results of the research technicians led to the use of these values rather than the supplier's. These values were used in determining the maximum theoretical specific gravity for each of the 24 Marshall briquets which are presented in Table IV. The procedure for determining the maximum theoretical specific gravity was in accordance with the FAA Eastern Region Laboratory Procedures Manual (ERLPM). An example calculation is presented in Appendix A.

Testing Procedures

The laboratory procedures followed in preparing, mixing, weighing, and testing of the Marshall briquets were in accordance with the procedures outlined in Section 2 of the ERLPM with only one exception. A piece of filter paper was placed on top of the asphaltic concrete mixture immediately prior to compacting the first side of the briquet to prevent material from adhering to the compaction hammer. The laboratory procedures for the FAA Eastern Region are the same as those outlined in developing a job mix formula in The Asphalt Institute's Manual Series No. 2 (MS-2) Mix Design Methods for Asphalt Concrete (10) publication with the following exceptions:

1. The FAA Eastern Region specifies the compaction temperatures as 250°+/- 5°F whereas MS-2 specifies the compaction temperature as the temperature that produces a kinematic viscosity of 280 +/- 30 centistokes.

2. The FAA Eastern Region permits reheating the aggregate and asphalt mixture to 250°+/- 5°F for compaction if the container is covered to prevent oxidation and the temperature is not below 200°F. The MS-2 manual does not allow reheating.

3. The FAA Eastern Region specifies the temperature of the breaking head to be maintained from 100°F to 140°F whereas MS-2 specifies 70°F to 100°F.

4. The method for determining the optimum asphalt content differs, and is explained in a later section of this report.

Before the mixing and testing of briquets could begin, several preliminary decisions had to be made. A weight of 1,155.7 grams was needed, based on practice replicates, to obtain the required 2.5-inch thickness for the Marshall briquets. From the asphalt viscosity curve in Figure 9, the mixing temperature at 170 +/- 20 centistokes was determined to be 297°F to 307°F. After these preliminary decisions were resolved, mixing and testing began and continued for approximately 8 weeks.

Table III. Specific Gravity and Absorption Values for Aggregates Used

Aggregate	Limestone (coarse)	Limestone (fine)	Natural Sand
Supplier's Lab			
Apparent Specific Gravity	2.715	2.646	2.660
Percent Absorption	0.69%	-----	-----
Research Lab			
Apparent Specific Gravity	2.700	2.684	2.660
Percent Absorption	0.73%	1.40%	1.30%

Table IV. Marshall Briquet Maximum Theoretical Specific Gravities

Gradation	Asphalt Content %	Max. Theoretical Specific Gravity
JMF	5.0	2.483
	5.5	2.464
	6.0	2.446
	6.5	2.428
	7.0	2.410
	7.5	2.393
FAAL	5.0	2.484
	5.5	2.465
	6.0	2.447
	6.5	2.429
	7.0	2.411
	7.5	2.394
FAAM	5.0	2.483
	5.5	2.464
	6.0	2.446
	6.5	2.428
	7.0	2.410
	7.5	2.393
FAAU	5.0	2.482
	5.5	2.464
	6.0	2.445
	6.5	2.427
	7.0	2.409
	7.5	2.392

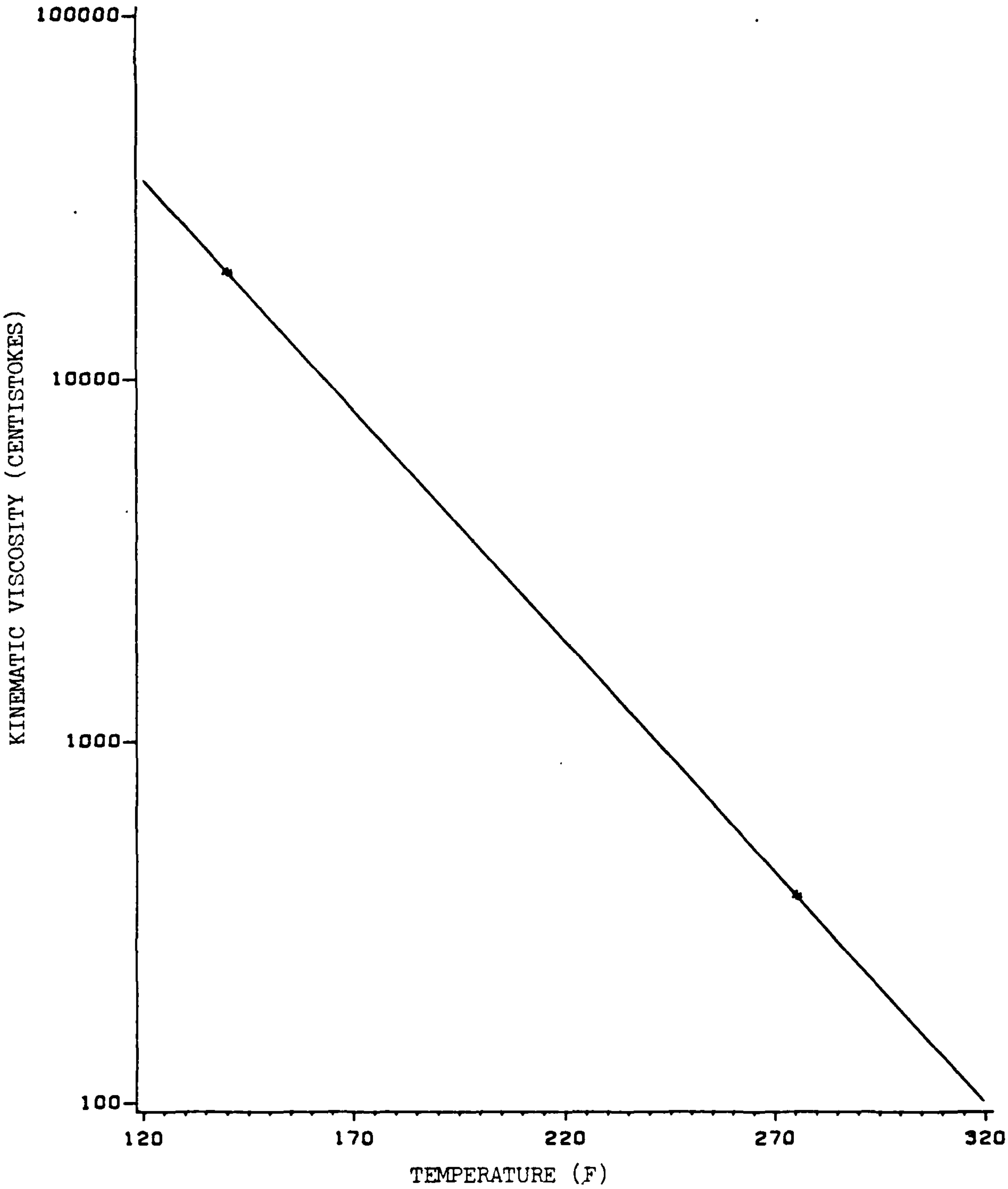


Figure 9. AC-20 Asphalt Cement Viscosity Curve

CHAPTER III

DATA ANALYSIS

After the 12 replicates of Marshall briquets had been mixed and tested, and the results stored in the computer, the analysis of the data could begin. Various programs within the Statistical Analysis System (SAS), a commercially available package of statistical programs, were used. An analysis of variance (ANOVA) and Duncan's Multiple Range Test were performed first to determine whether time, i.e., order of testing, had an effect on the results. Then, the Marshall properties were plotted against asphalt content, and a correlation analysis among the Marshall properties was performed.

Preparation

The computer was used for all data analysis, but before any analysis could be performed, the test results had to be stored and converted to usable data. All test data, including the asphalt, mixing, and compaction temperatures, were originally recorded on preprinted forms and then transferred to computer storage. A simple computer program was written to perform the necessary calculations in accordance with the ERLPM for determining the apparent specific gravity, percent voids in the total mix, percent voids filled, unit weight, and stability corrections due to briquet volume fluctuations. The refined data were arranged by gradation and asphalt content and are presented in Appendix B. SAS was utilized to manage the data and assist in the analysis.

Testing for Time Trend

An analysis of variance (ANOVA) and Duncan's Multiple Range Test were performed on the data. The primary reason for this analysis was to determine whether time had an effect on the data. Blocking for time, i.e., testing for differences in stability, flow, and air voids between replicates, using the ANOVA and Duncan's Multiple Range procedures in SAS revealed differences existed in the stability and flow results at the 0.05 significance level. In particular, Duncan's test indicated the stability and flow results were statistically significantly different from the other replicates for replicate 1, and the flow results were different for replicate 2. This was not conclusive enough to warrant the omission of any replicates from the data base. However, a correlation analysis of the Marshall properties with and without the first replicate was conducted. This analysis indicated a notable difference in the correlation coefficients determined with and without replicate 1. It was therefore decided that the first replicate should be deleted. The correlation coefficiets among the properties with and without the first replicate are shown in Table V and in Figures 10-12 and 13-15, respectively.

Table V. Correlations Results Using All 12 Replicates (12 Reps) and Using Only Replicates 2-12 (11 Reps)

Gradation	Asphalt Content	Stability vs. Flow		Stability vs. Air Voids		Flow vs. Air Voids	
		12 Reps	11 Reps	12 Reps	11 Reps	12 Reps	11 Reps
FAA LOWER	5.0	0.511	0.582	-0.547	-0.594	0.126	-0.035
	5.5	0.316	0.360	-0.446	-0.296	-0.152	-0.264
	6.0	0.676	0.781	-0.268	-0.290	-0.440	-0.438
	6.5	0.665	0.713	0.328	0.121	-0.289	-0.390
	7.0	0.368	0.373	-0.274	-0.276	0.076	0.056
	7.5	-0.274	-0.273	-0.489	-0.542	0.359	0.417
FAA MIDPOINT	5.0	0.386	0.506	-0.519	-0.538	0.294	0.052
	5.5	0.582	0.593	-0.276	-0.416	0.007	-0.239
	6.0	-0.527	-0.591	0.261	0.275	-0.454	-0.456
	6.5	0.080	0.040	0.489	0.370	-0.502	-0.736
	7.0	-0.123	0.195	0.233	-0.007	-0.552	-0.458
	7.5	0.077	0.040	-0.281	-0.402	-0.104	-0.222
FAA UPPER	5.0	0.118	0.112	-0.413	-0.400	-0.511	-0.510
	5.5	0.341	-0.031	-0.666	-0.525	-0.589	-0.465
	6.0	-0.416	-0.391	0.383	0.357	-0.865	-0.931
	6.5	-0.421	-0.278	0.506	0.011	-0.812	-0.814
	7.0	-0.684	-0.690	0.485	0.483	-0.481	-0.481
	7.5	0.015	-0.062	-0.095	0.019	-0.669	-0.661
JMF	5.0	0.634	0.281	-0.855	-0.576	-0.692	-0.362
	5.5	0.198	-0.090	-0.771	-0.702	-0.088	+0.577
	6.0	0.181	-0.097	-0.701	-0.762	-0.509	0.138
	6.5	0.312	0.003	-0.646	-0.722	-0.907	-0.611
	7.0	-0.327	-0.391	-0.230	-0.439	-0.504	0.149
	7.5	-0.108	0.282	-0.116	-0.354	-0.882	-0.794

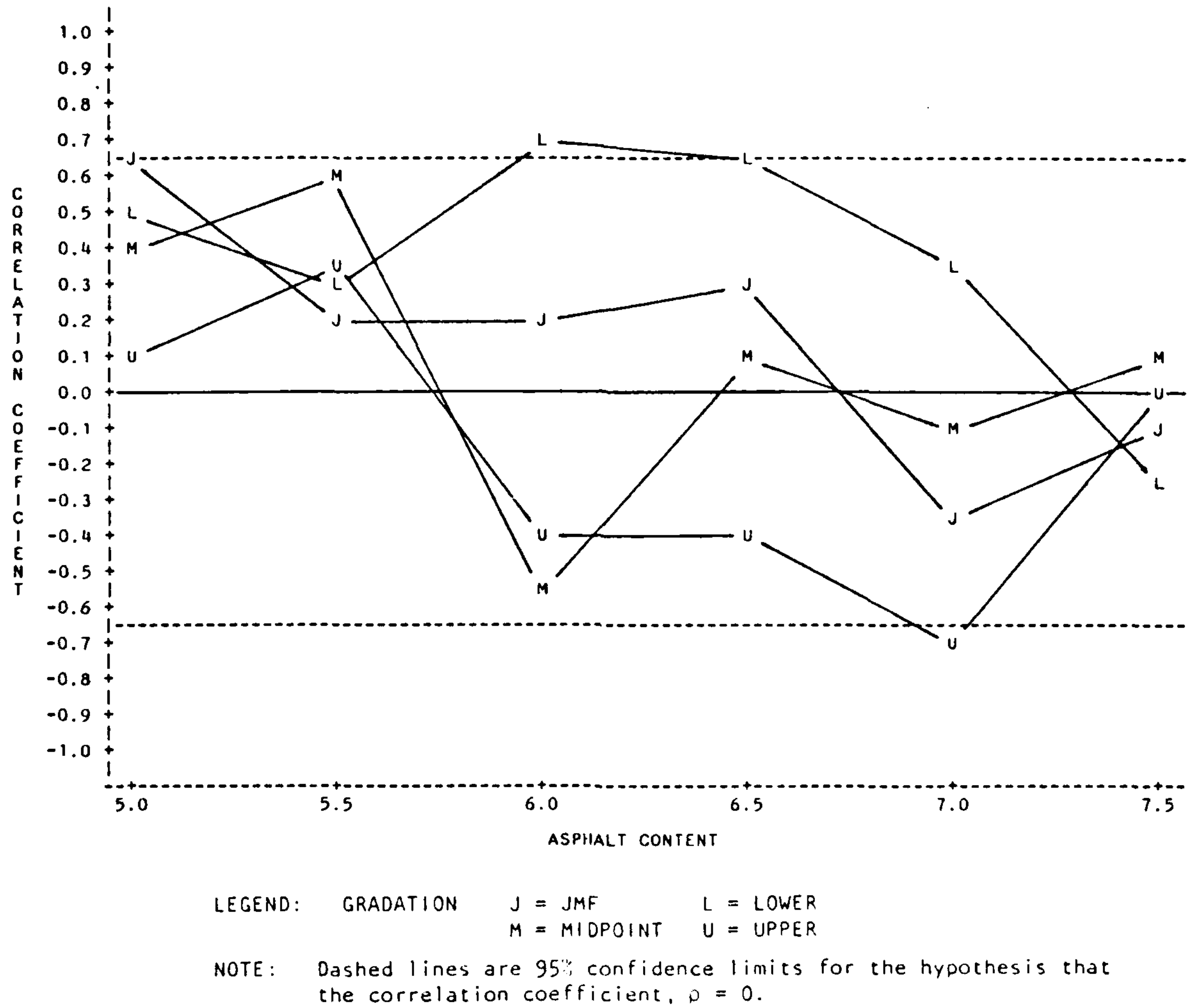
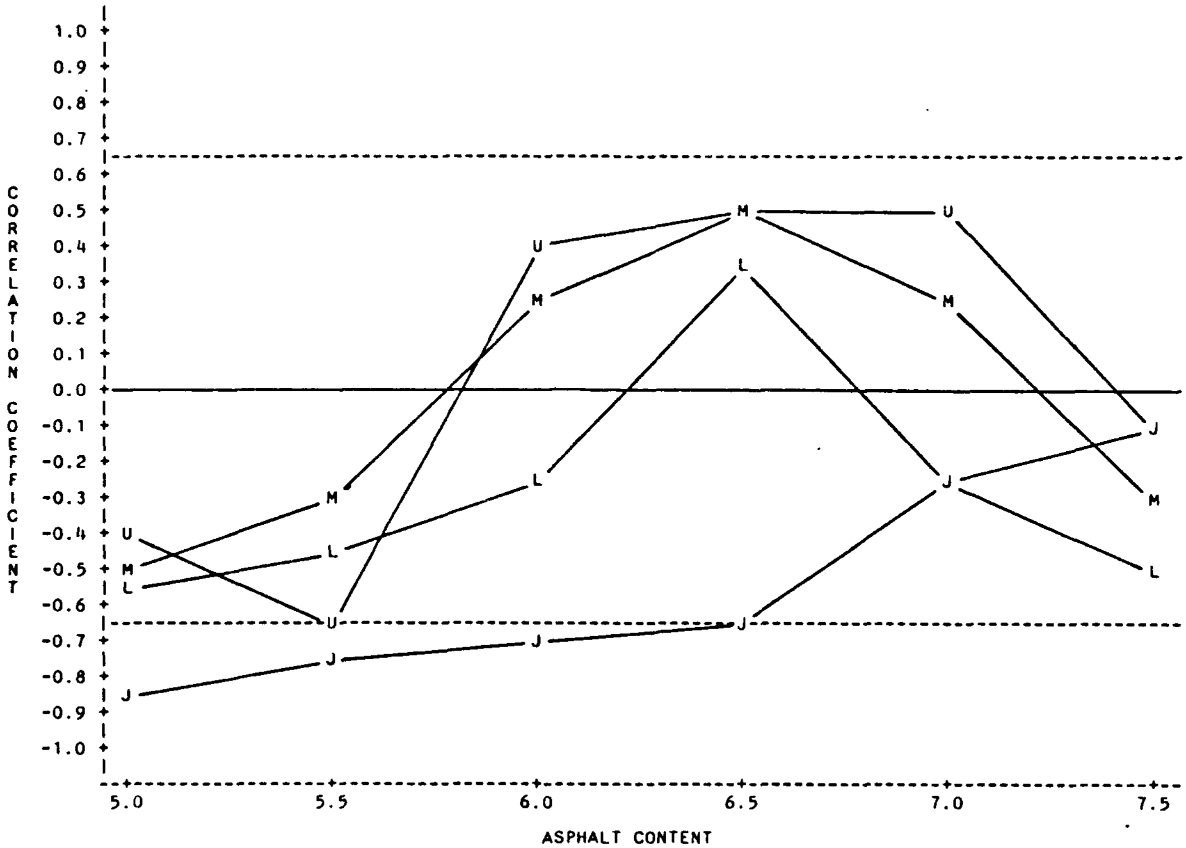


Figure 10. Stability vs. Flow Correlation Coefficient Plots Using All 12 Replicates



LEGEND: GRADATION J = JMF L = LOWER
M = MIDPOINT U = UPPER

NOTE: Dashed lines are 95% confidence limits for the hypothesis that the correlation coefficient, $\rho = 0$.

Figure 11. Stability vs. Air Voids Correlation Coefficient Plots Using All 12 Replicates

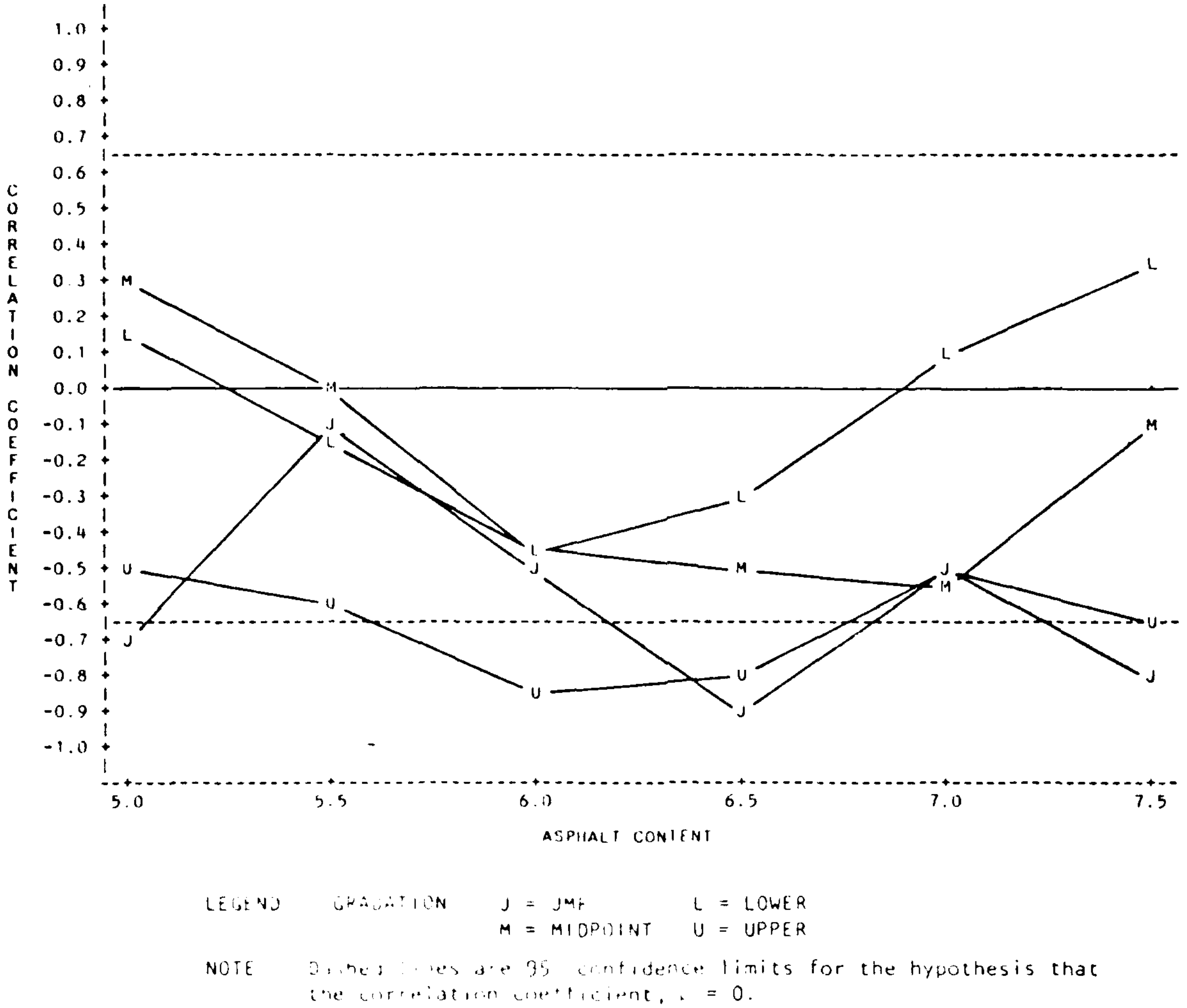
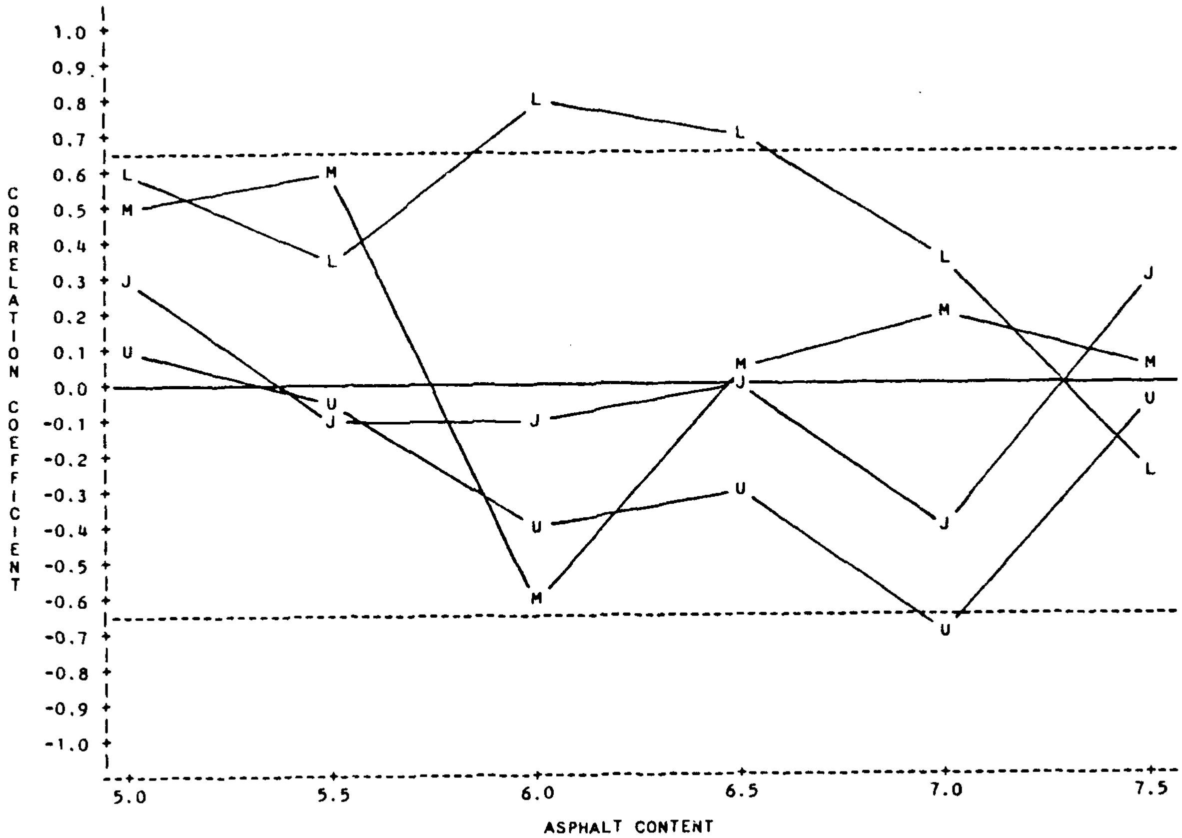


Figure 12. Flow vs. Air Voids Correlation Coefficient Plots Using All 12 Replicates



LEGEND: GRADATION J = JMF L = LOWER
M = MIDPOINT U = UPPER

NOTE: Dashed lines are 95% confidence limits for the hypothesis that the correlation coefficient, $\rho = 0$.

Figure 13. Stability vs. Flow Correlation Coefficient Plots Using Replicates 2-12

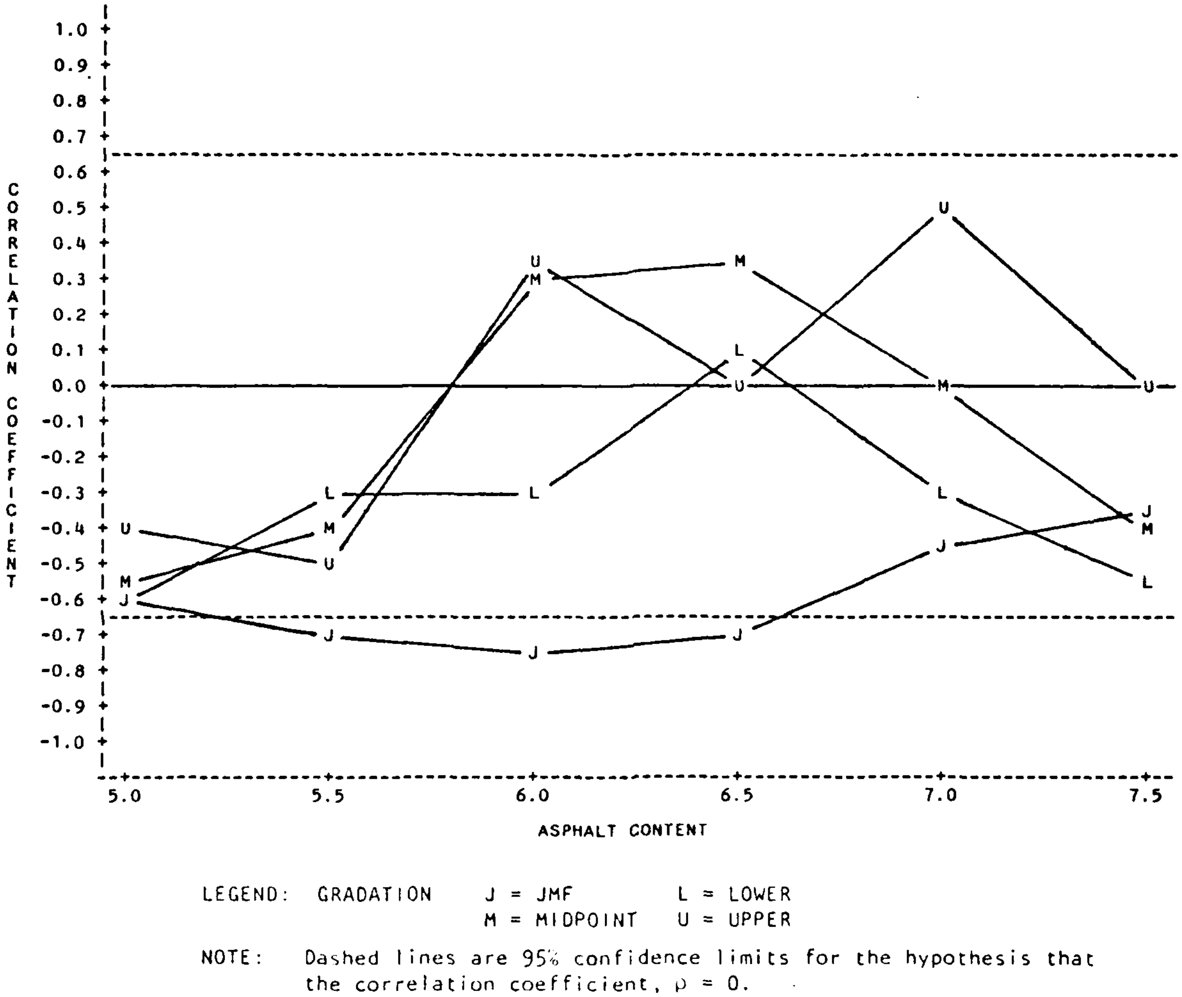
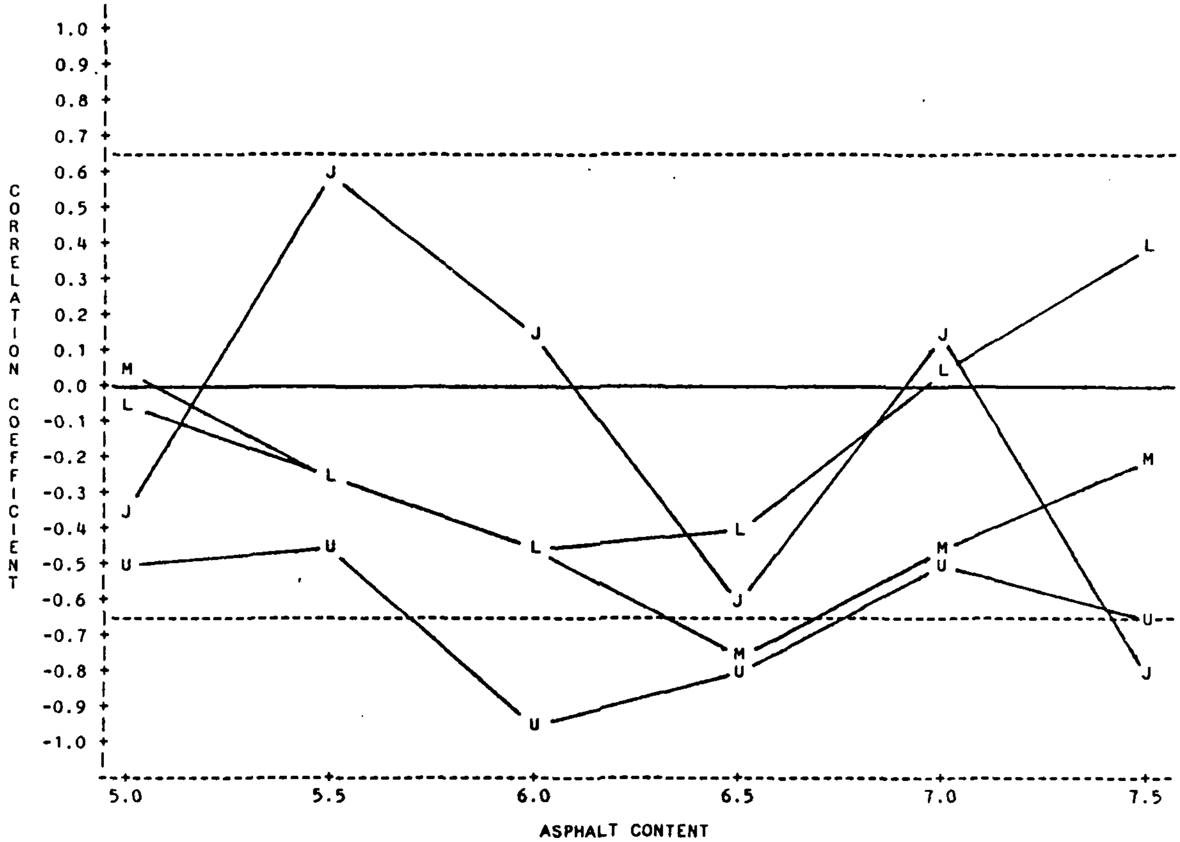


Figure 14. Stability vs. Air Voids Correlation Coefficient Plots Using Replicates 2-12



LEGEND: GRADATION J = JMF L = LOWER
M = MIDPOINT U = UPPER

NOTE: Dashed lines are 95% confidence limits for the hypothesis that the correlation coefficient, $\rho = 0$.

Figure 15. Flow vs. Air Voids Correlation Coefficient Plots Using Replicates 2-12

At this point, a more detailed investigation of the scatter plots of the properties for each gradation at each asphalt content was conducted. This investigation revealed a significant number of outliers from replicates 2 and 3 influencing the correlation coefficients. The scatter plots containing the outliers, with the outliers identified, are presented in Appendix C. The ANOVA results were reviewed and replicates 2 and 3 failed to show significant differences from the other replicates for stability, flow, or air voids. A third correlation analysis was performed deleting the first 3 replicates. The results of this analysis are shown in Table VI, and Figures 16-18. The analysis showed correlation coefficients markedly different from the coefficients in the previous analysis with replicates 2-12. Because of these differences, the first 3 replicates were eliminated from the correlation analysis.

Optimum Asphalt Content Determination and Marshall Property Comparisons

The Marshall properties, stability, flow, and air voids, were each plotted against asphalt content. This was performed primarily to determine the optimum asphalt content for each gradation and to compare the research data with the generally accepted plots of stability, flow, and air voids versus asphalt content. The first replicate was deleted from these plots for the reasons previously discussed.

Correlation Analysis

The objective of the research was to determine whether or not correlations exist among the Marshall properties. To be more specific, the research was intended to determine how well Marshall stability correlated with Marshall flow, Marshall stability correlated with air voids, and Marshall flow correlated with air voids for each gradation and asphalt content combination. Since each property appeared to be related to the optimum asphalt content, the correlation coefficients were plotted with each gradation adjusted for its respective optimum asphalt content.

A correlation coefficient is a measure of the amount of association between 2 variables. The correlations in this research effort were evaluated based on a linear relationship between 2 variables, and were defined by:

Table VI. Correlations Results Using Replicates 4-12

Gradation	Asphalt Content	Stability vs. Flow	Stability vs. Air Voids	Flow vs. Air Voids
FAA LOWER	5.0	0.449	-0.286	0.368
	5.5	0.522	-0.329	-0.010
	6.0	0.860	-0.415	-0.495
	6.5	0.644	0.378	-0.137
	7.0	0.770	0.133	-0.256
	7.5	-0.263	-0.619	-0.023
FAA MIDPOINT	5.0	0.645	-0.532	-0.220
	5.5	0.422	0.444	0.084
	6.0	0.116	-0.200	-0.682
	6.5	0.674	-0.010	-0.184
	7.0	0.692	-0.401	-0.148
	7.5	0.350	-0.532	-0.252
FAA UPPER	5.0	0.298	-0.416	-0.529
	5.5	-0.223	-0.396	-0.308
	6.0	0.278	-0.473	-0.753
	6.5	-0.005	-0.113	-0.767
	7.0	-0.547	-0.407	0.017
	7.5	0.540	-0.631	-0.345
JMF	5.0	0.006	-0.156	-0.147
	5.5	0.048	-0.601	0.537
	6.0	0.282	-0.643	-0.493
	6.5	0.032	-0.635	-0.731
	7.0	-0.260	-0.515	0.306
	7.5	0.383	-0.457	-0.688

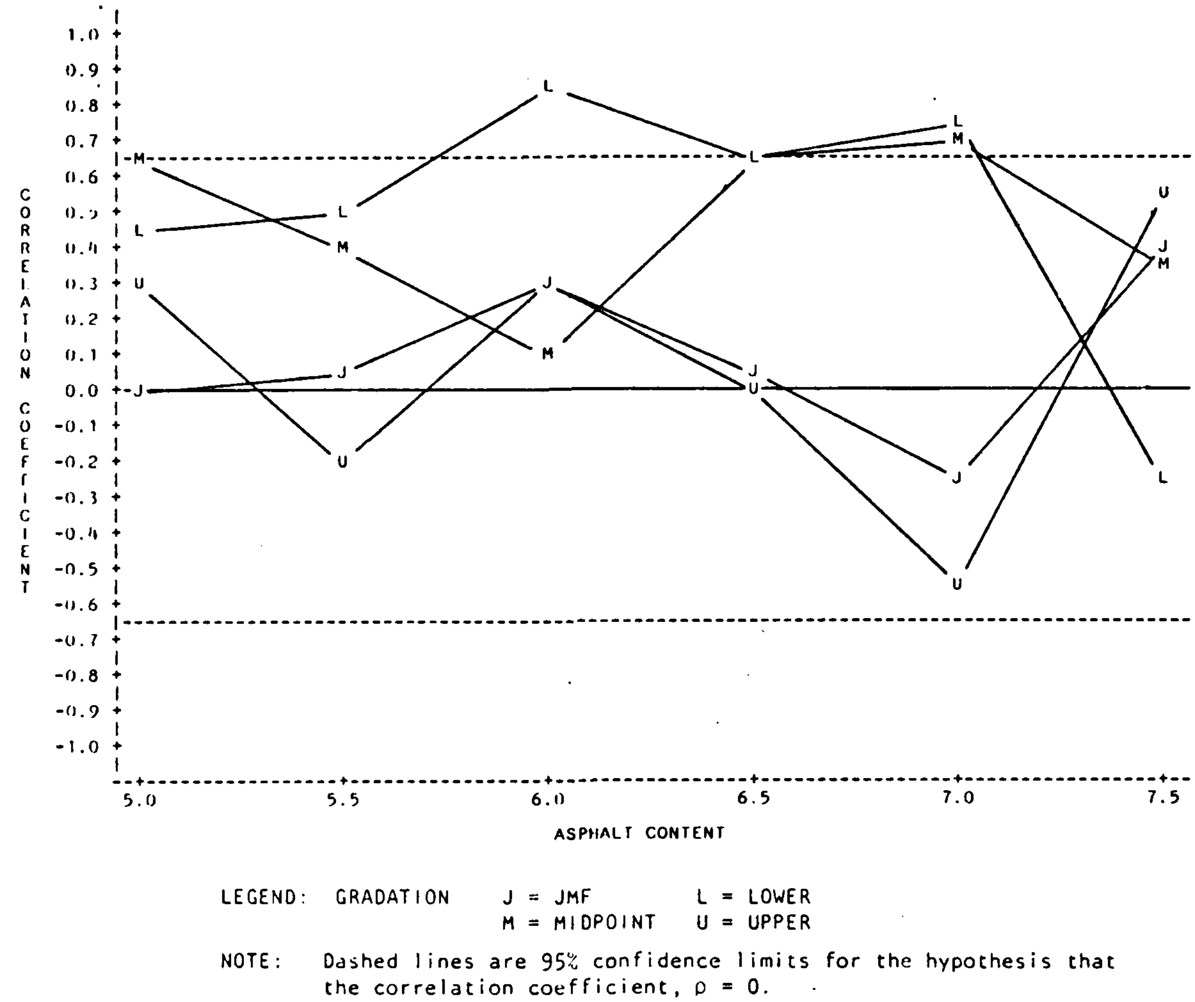


Figure 16. Stability vs. Flow Correlation Coefficient Plots Using Replicates 4-12

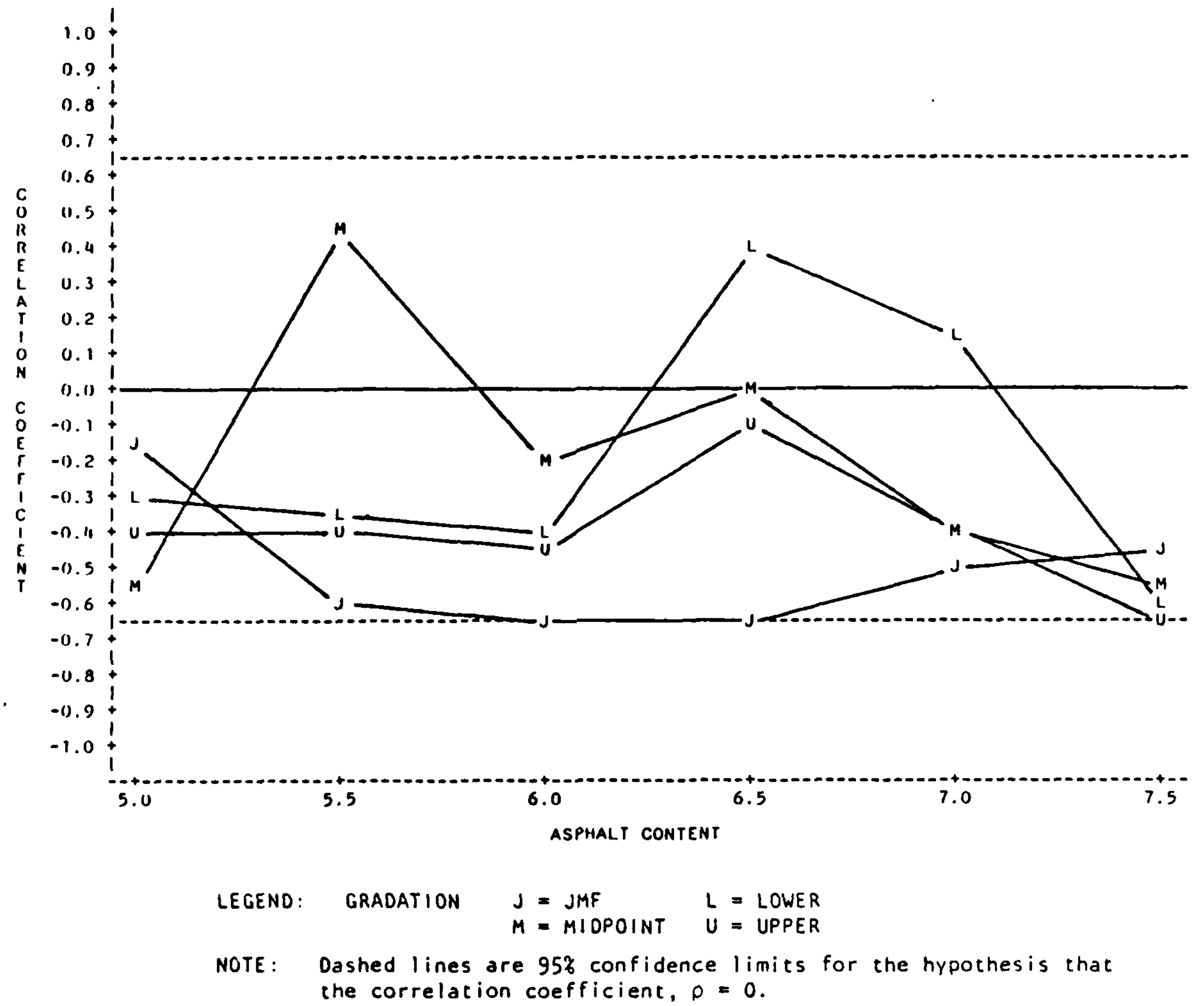
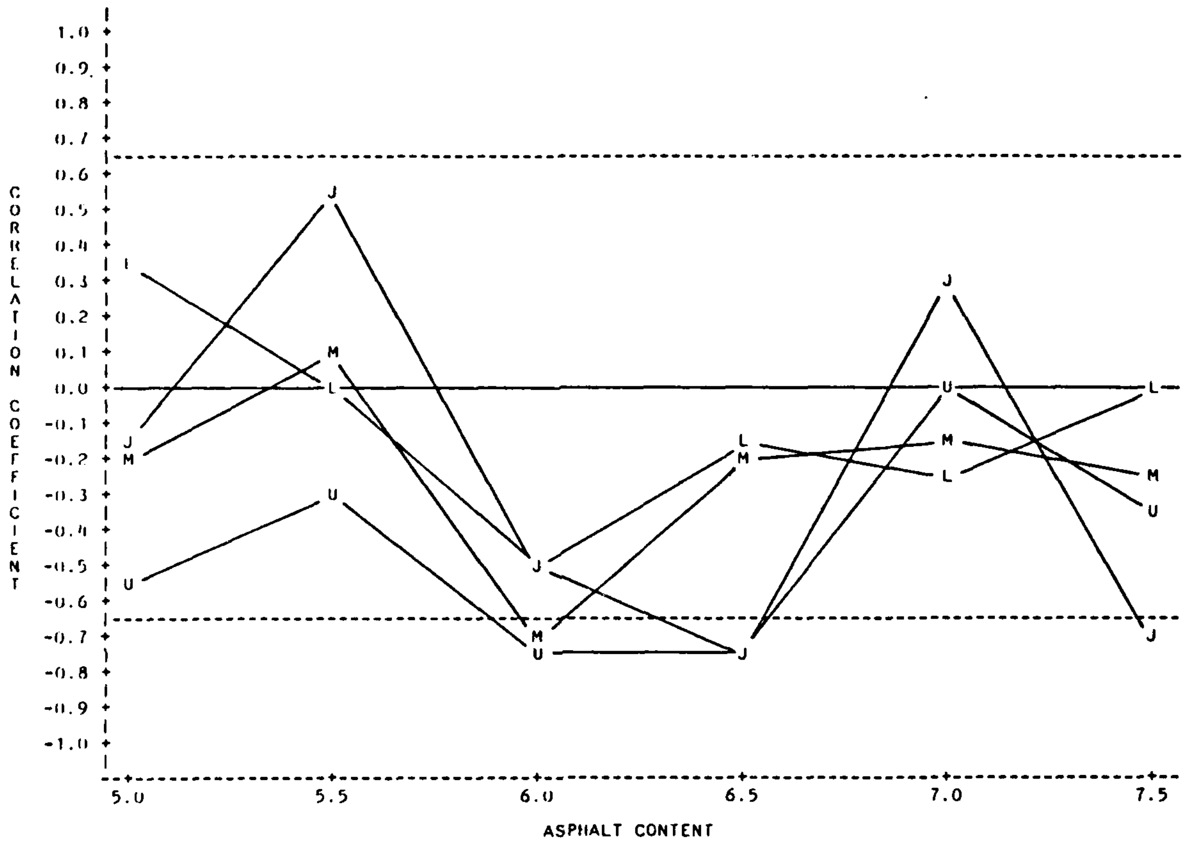


Figure 17. Stability vs. Air Voids Correlation Coefficient Plots Using Replicates 4-12



LEGEND: GRADATION J = JMF L = LOWER
M = MIDPOINT U = UPPER

NOTE: Dashed lines are 95% confidence limits for the hypothesis that the correlation coefficient, $\rho = 0$.

Figure 18. Flow vs. Air Voids Correlation Coefficient Plots Using Replicates 4-12

$$r = \frac{\sum_{i=1}^{N} (X_i-\bar{X})(Y_i-\bar{Y})}{\sqrt{\sum_{i=1}^{N} (X_i-\bar{X})^2 \sum_{i=1}^{N} (Y_i-\bar{Y})^2}}$$

where:

r = sample correlation coefficient
N = number of samples
X = one variable
$\bar{X}$ = mean of X_i variables
Y = the other variable
$\bar{Y}$ = mean of Y_i variables

The sample correlation coefficient (r) can range from -1.0 (exact negative correlation) to +1.0 (exact positive correlation). When the sample data are scattered or form either a horizontal or vertical line, the $(X-\bar{X})(Y-\bar{Y})$ cross products will be approximately half positive and half negative, the sum of which will be close to zero, resulting in a low correlation coefficient. But, for variables showing a near one-to-one relationship, the sum of the cross products, $(X-\bar{X})(Y-\bar{Y})$, is either positive for a direct correlation or negative for an inverse correlation, and approaches the magnitude of the denominator in the equation, thereby resulting in a high correlation coefficient, i.e., one close to +1.0 or -1.0.

Only 9 replicates were used for the correlation analysis, because, as discussed previously, outliers in the first 3 replicates caused the correlations among the properties based on 12 replicates to vary markedly from the correlations based on 9 replicates. Therefore, referring to Figure 6 presenting the power curves, there is a 0.4 probability of detecting a correlation if the true population correlation coefficient between 2 parameters is 0.5. If the true population correlation coefficient is 0.7, then there is a 0.7 probability of detecting a correlation.

CHAPTER IV

DATA ANALYSIS RESULTS

In this chapter, the results of the data analysis are presented. Some of the findings were as expected, while other results were unexpected. The results of the optimum asphalt content determination are presented first, followed by the results of the correlation analysis.

Marshall Properties-Asphalt Content Relationships

The primary purpose in plotting the Marshall stability, flow, and air voids against the percent asphalt content was to determine the optimum asphalt content for each gradation and to compare the research data with the accepted plots of the Marshall properties published in MS-2 (10).

The comparison of the Marshall property plots was conducted first since several of these plots were required to determine the optimum asphalt content for each gradation. Typical plots of stability, flow, and air voids versus asphalt content as presented in MS-2 are shown in Figure 19. The patterns exhibited by the properties in Figure 19 are also present in the research data.

Stability versus Asphalt Content

In the stability versus asphalt content plots (Figures 20-23), stability increases to a maximum and then decreases as the percent asphalt content is increased. The horizontal reference line at 1,800 pounds corresponds to the minimum specification limit for the FAA Eastern Region. In Figure 20, the maximum stability would be somewhere below 5.0% asphalt content. Another interesting point to be made is the range, i.e., the difference in the minimum and maximum values, in the stability values among gradations for a given asphalt content.

All stability means for each gradation and asphalt content are within the spcificaton limits excent the mean for the Midpoint gradation at 7.5% asphalt content. However, the stability may have a range as large as 700 to 800 pounds for a given gradation and asphalt content. For instance, the stability results for the Lower gradation at 5.0% asphalt content vary from 2,130 to 2,890 pounds; a range of 720 pounds. The smallest range in stability for a given gradation and asphalt content is 165 pounds, which is from the results of the JMF gradation at 7.5% asphalt content. Although the stability results appear to vary significantly, the standard deviation for each asphalt content varies between 53 and 224 pounds with a mean standard deviation of 137.2 pounds for all asphalt contents and gradations. The standard deviation generally decreases as percent asphalt content increases. A summary of the statistics for all gradations is presented in Appendix E.

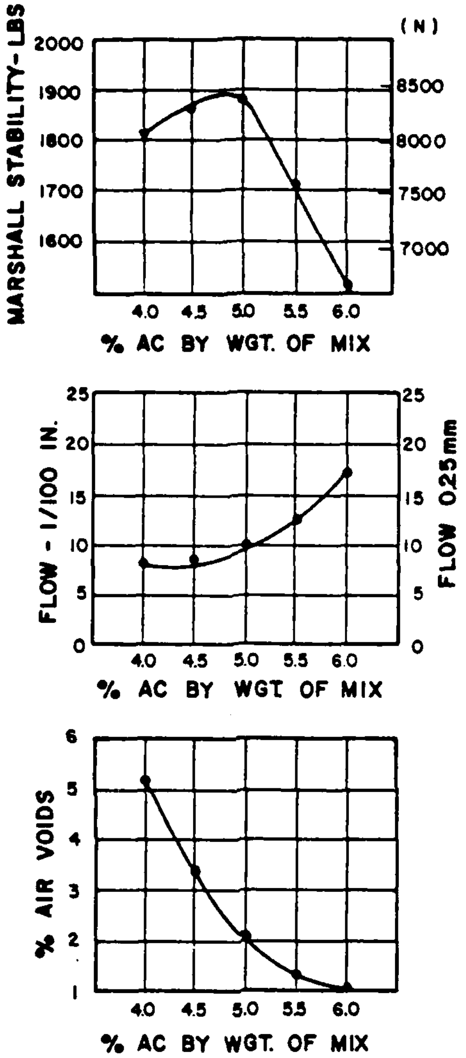


Figure 19. Marshall Property Plots from The Asphalt Institute's MS-2 Manual (10)

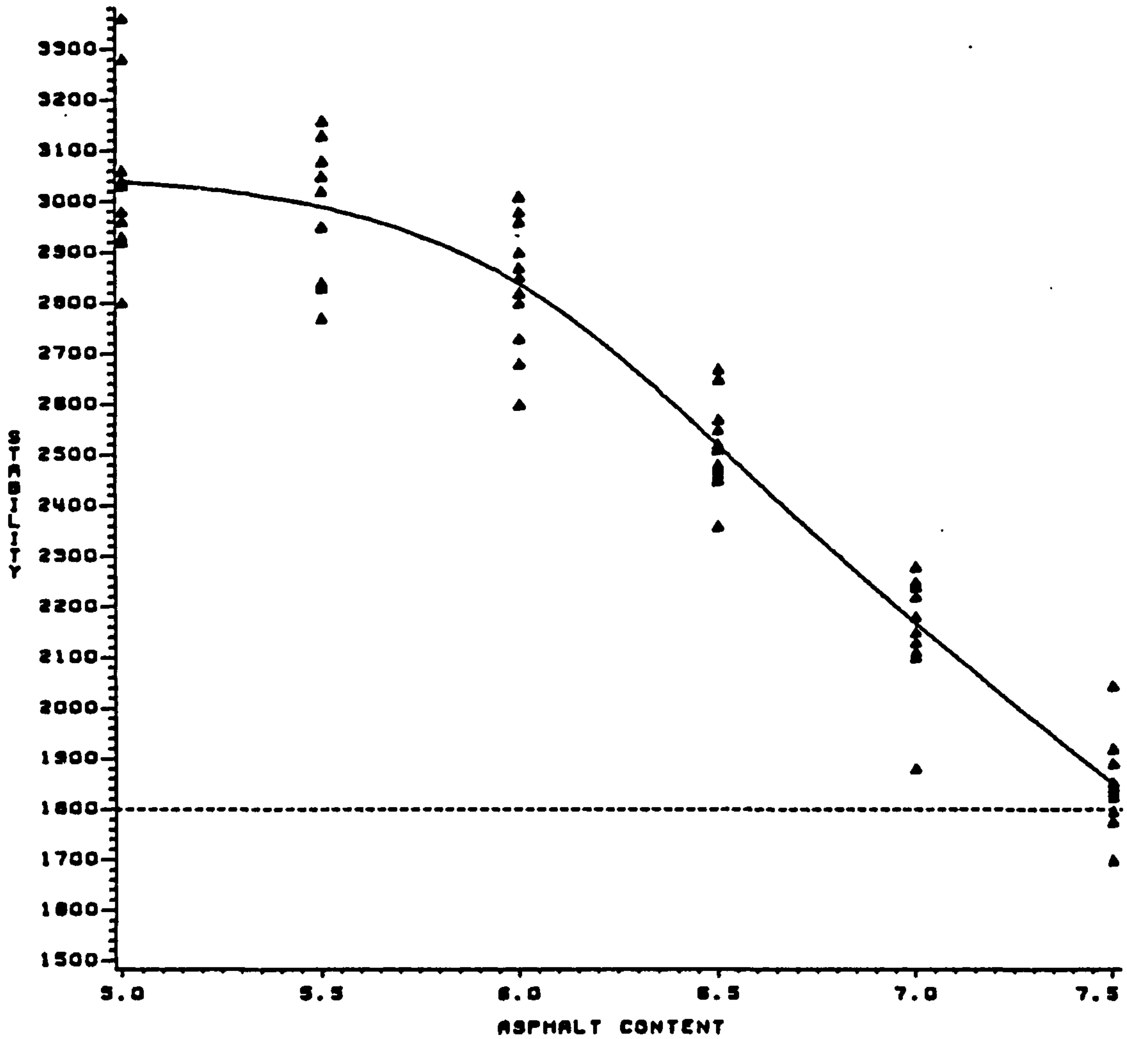


Figure 20. Stability vs. Asphalt Content: FAA Upper Gradation

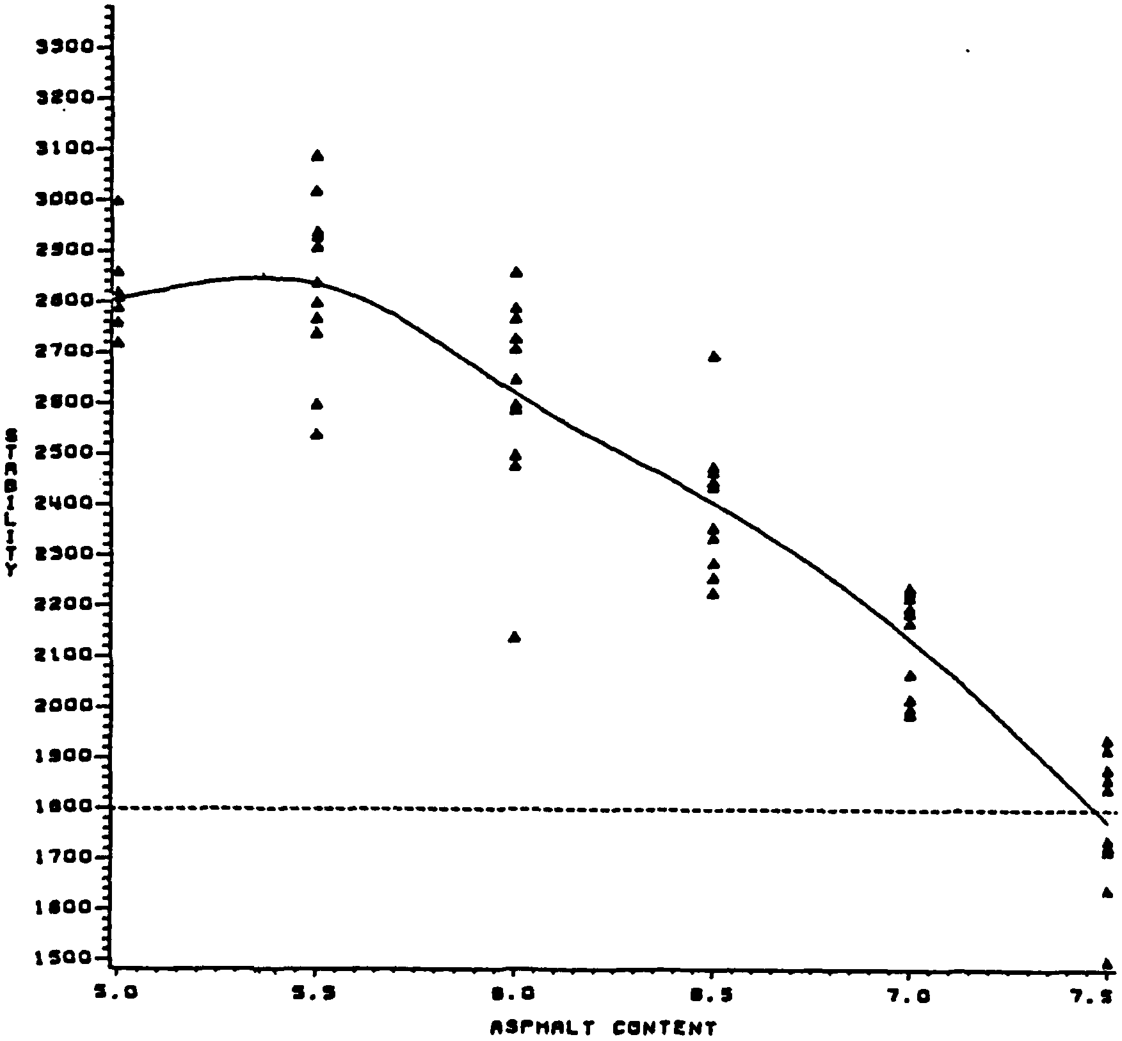


Figure 21. Stability vs. Asphalt Content: FAA Midpoint Gradation

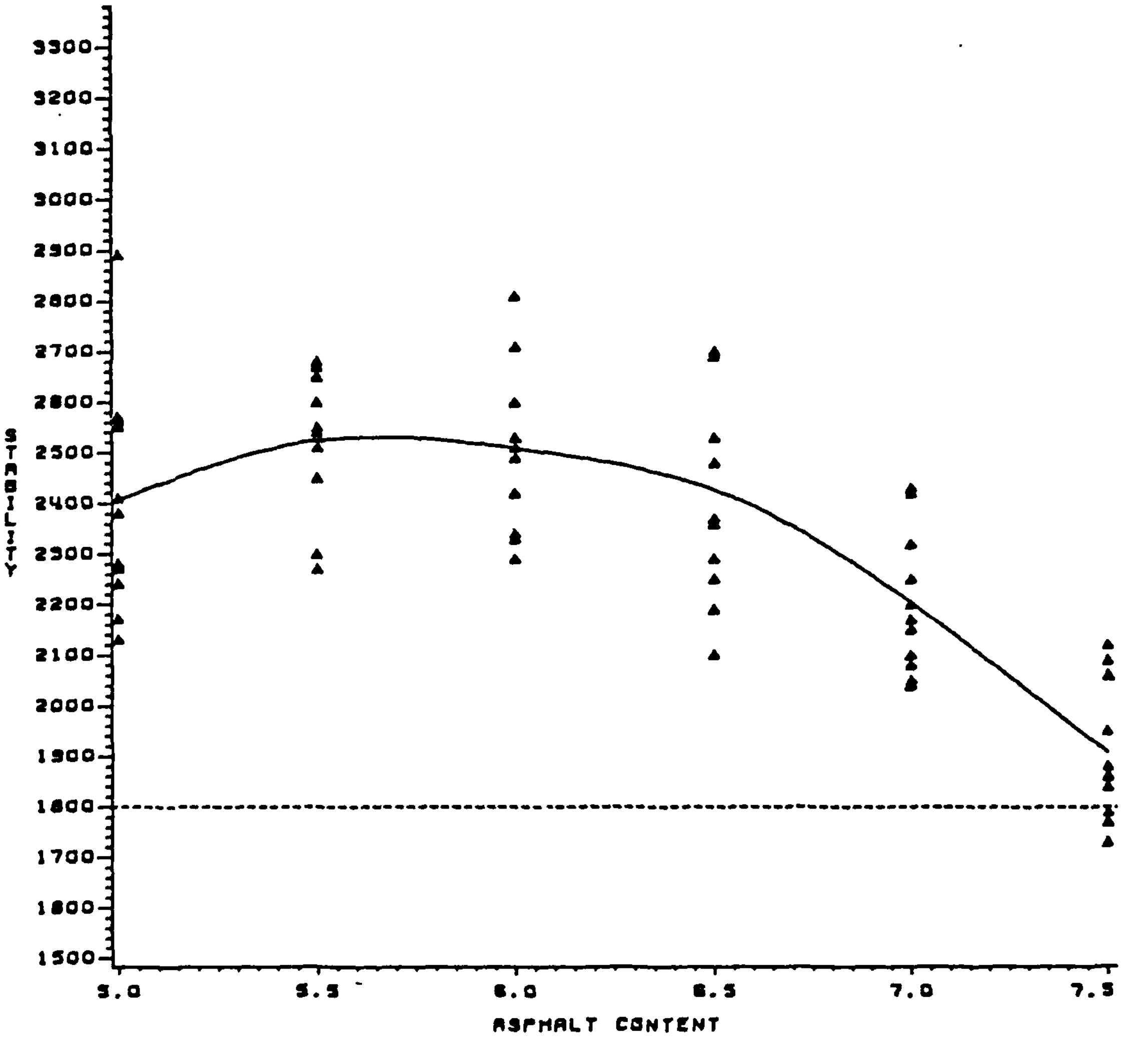


Figure 22. Stability vs. Asphalt Content: FAA Lower Gradation

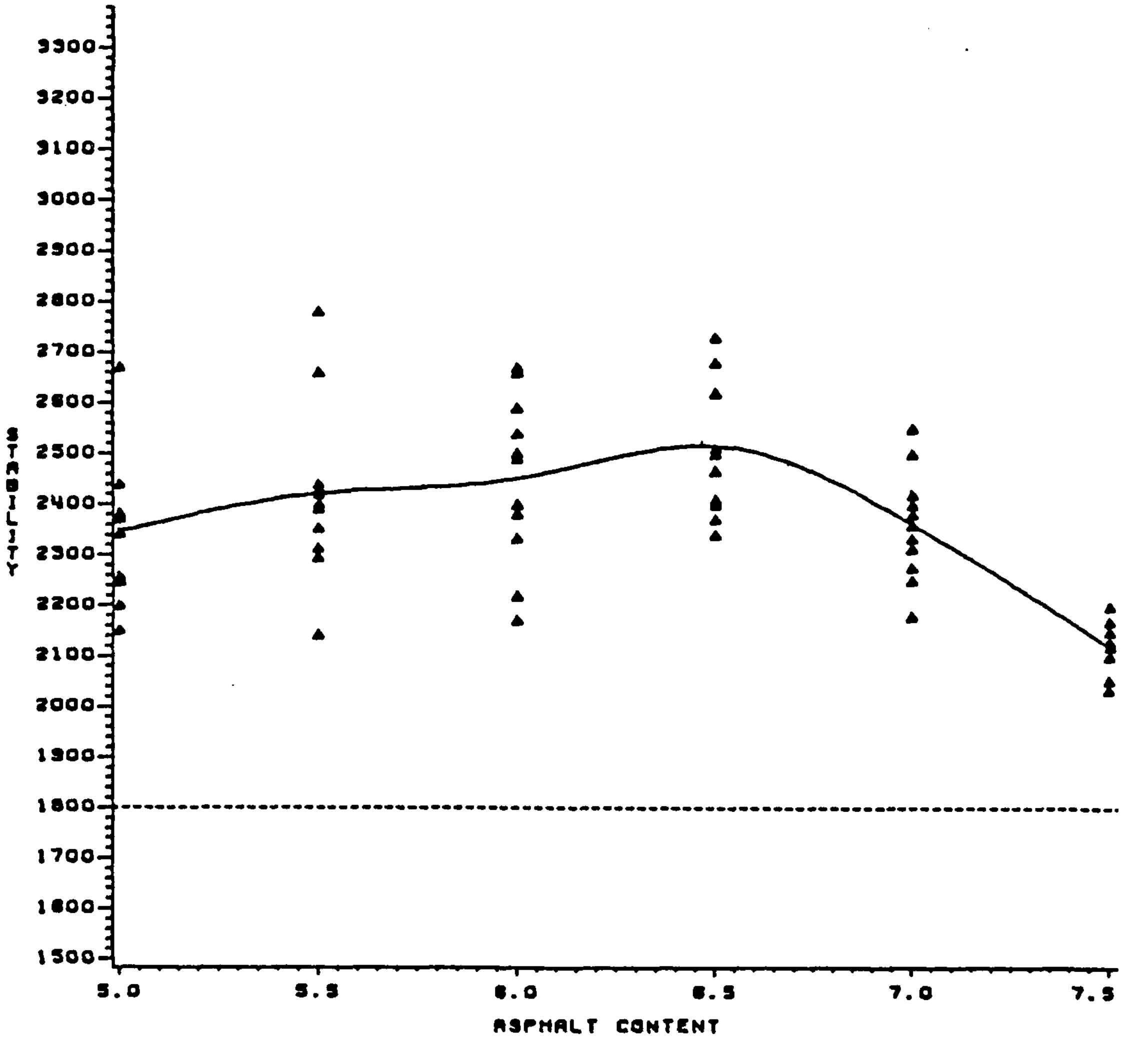


Figure 23. Stability vs. Asphalt Content: JMF Gradation

Flow versus Asphalt Content

In the flow versus asphalt content plots (Figures 24-27), the flow increases with increasing asphalt content, as indicated in MS-2. The horizontal reference lines at flows of 8 and 16 correspond to the minimum and maximum specification limits for the FAA Eastern Region. All mean flows for each gradation and asphalt content are above the minimum specification limit. However, the mean flow for the Upper and Midpoint gradations above 6.5% asphalt content and mean flow for the Lower and JMF gradations above 7.0% asphalt content are also above the maximum specification limit.

As the mean flow for each asphalt content increases with increasing percent asphalt content, the range in the flow values tends to increase. The maximum range for flow, which occurs in the Upper gradation at 7.5% asphalt content, is 5.5 (1/100-inch). The minimum range for flow is 1.3 (1/100-inch) for the JMF gradation at 5.0% asphalt content. The standard deviation, like the range, generally increases with increasing percent asphalt content. A summary of the statistics for all gradations is presented in Appendix F.

Air Voids versus Asphalt Content

In the air voids versus asphalt content plots (Figures 28-31), the air voids decrease as the asphalt content increases and then gradually level off at approximately 1 to 2 percent depending on the gradation. The horizontal reference lines at air voids of 2 and 5 percent are the minimum and maximum specification limits for the Eastern Region. The air voids means for all gradations at 5.0% asphalt content are above the maximum specification limit. At 6.5% asphalt content, the air voids means are below the minimum specification limit for the Upper, Midpoint, and Lower gradations, while the JMF gradation air voids mean does not fall below the minimum specification limit until 7.5% asphalt content.

The range in air voids at each asphalt content, like the range in stability, tends to decrease with increasing percent asphalt content. The maximum range in air voids is 2.75%, which occurs in the Lower gradation at 5.0% asphalt content. The minimum range in air voids is 0.26%, which is for the Lower gradation at 7.0% asphalt content. The range at 7.5% asphalt content for the same gradaton is only slightly higher (0.29%). The standard deviation for each asphalt content varies from 0.08% to 0.71%, with a mean standard deviation of 0.23%. The standard deviation for air voids generally decreases with increasing percent asphalt content. A summary of the statistics for all gradations is presented in Appendix G.

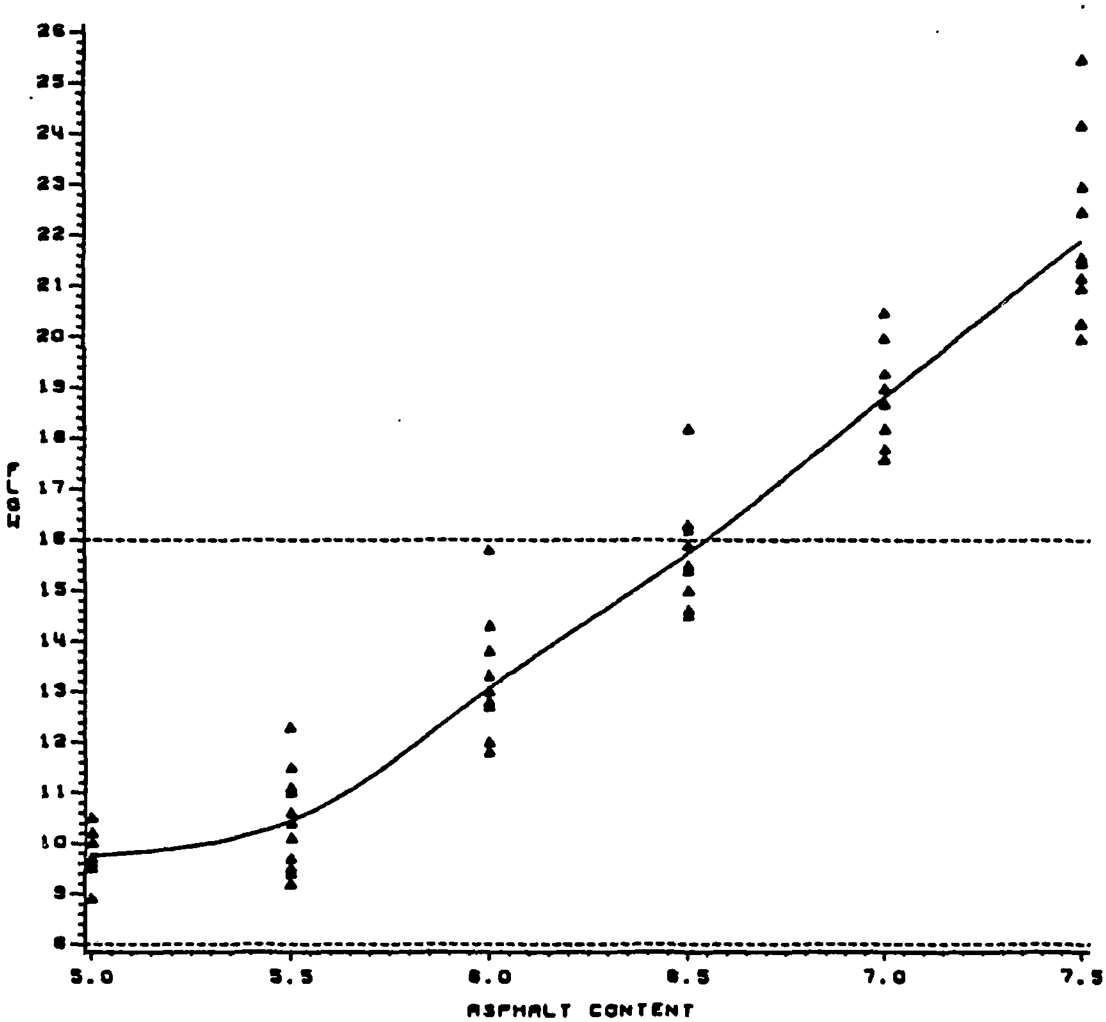


Figure 24. Flow vs. Asphalt Content: FAA Upper Gradation

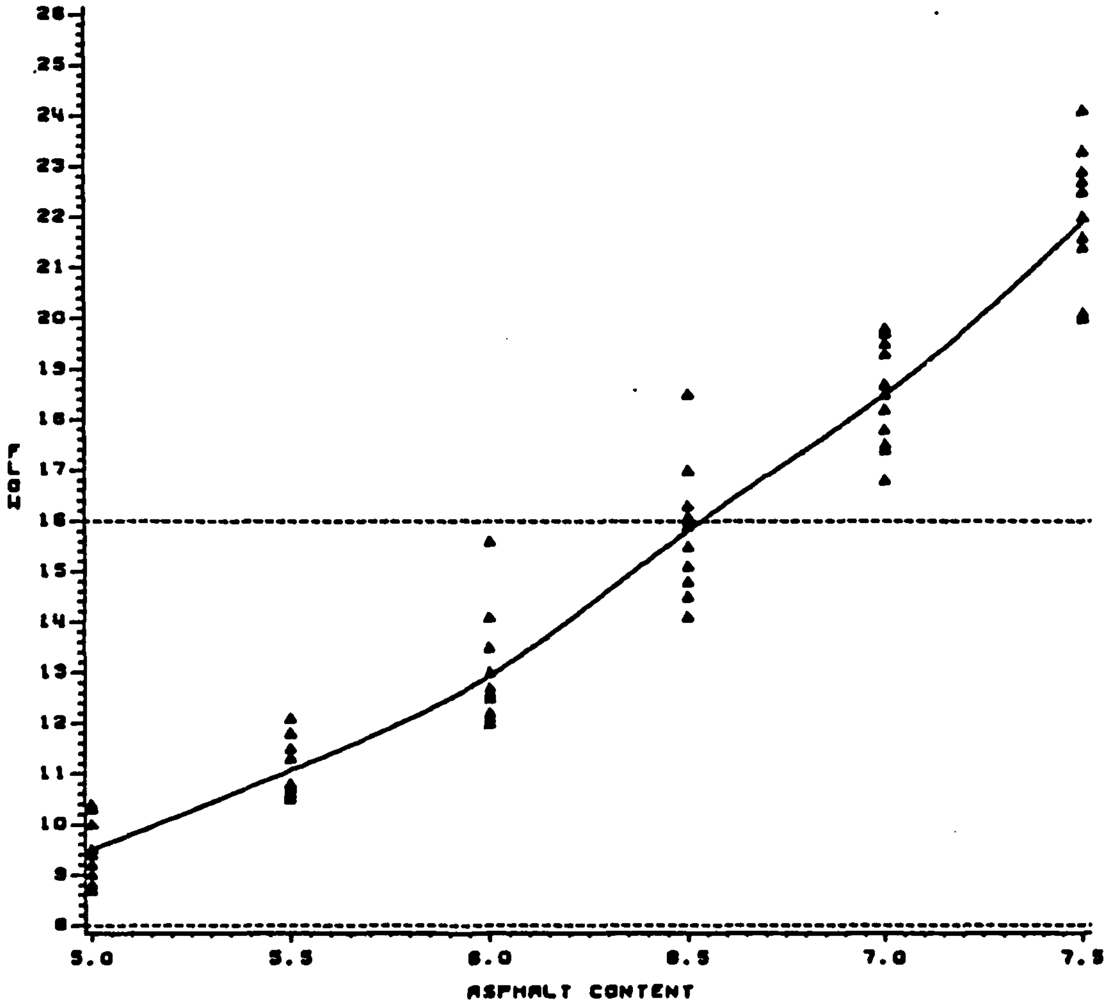


Figure 25. Flow vs. Asphalt Content: FAA Midpoint Gradation

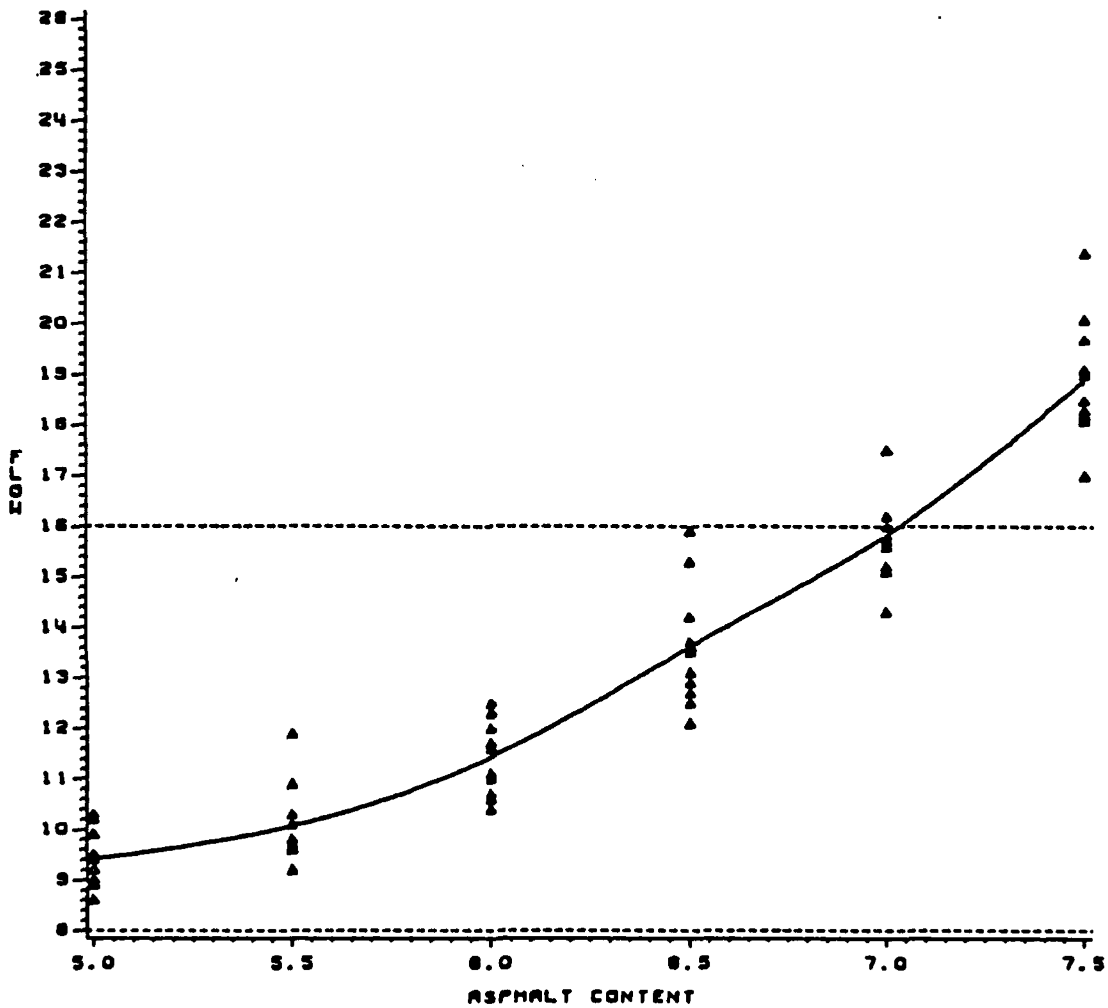


Figure 26. Flow vs. Asphalt Content: FAA Lower Gradation

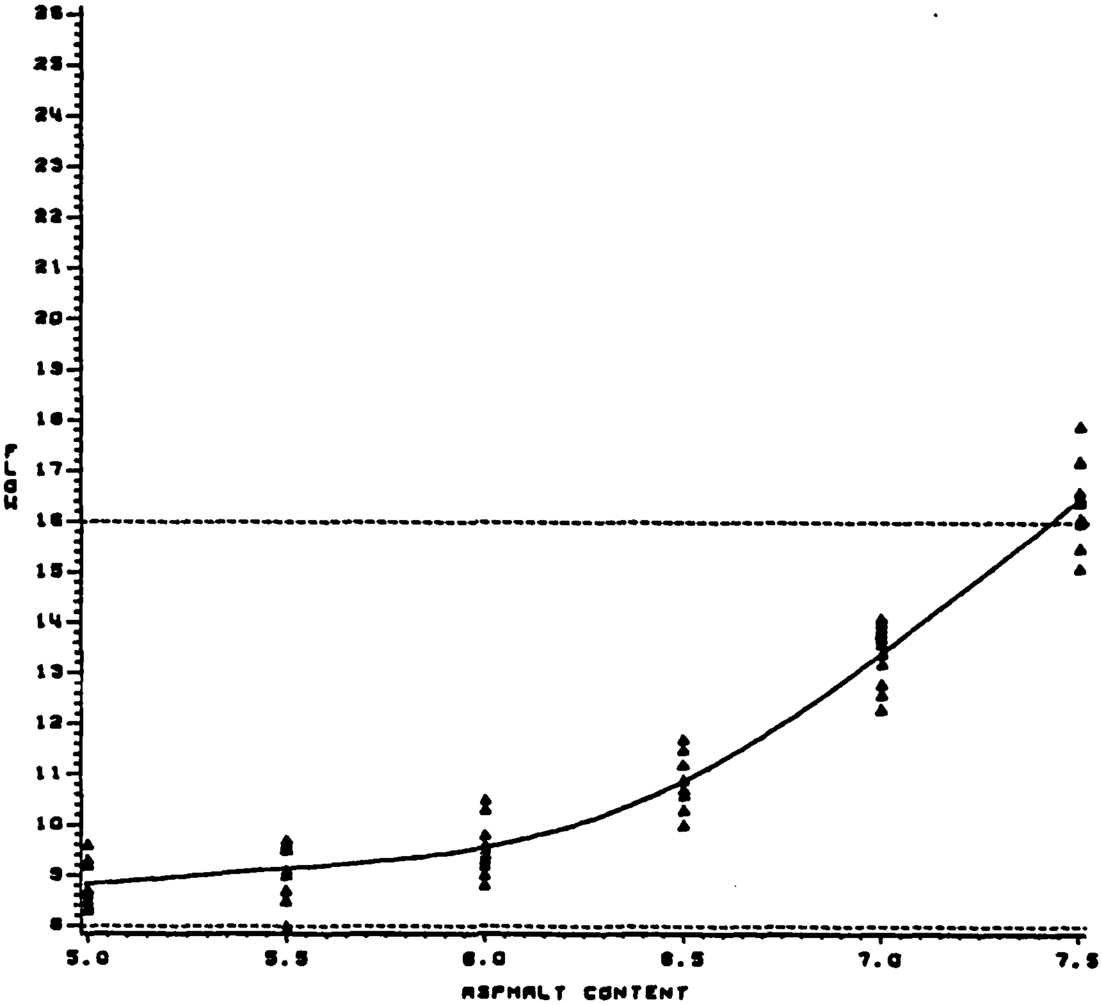


Figure 27. Flow vs. Asphalt Content: JMF Gradation

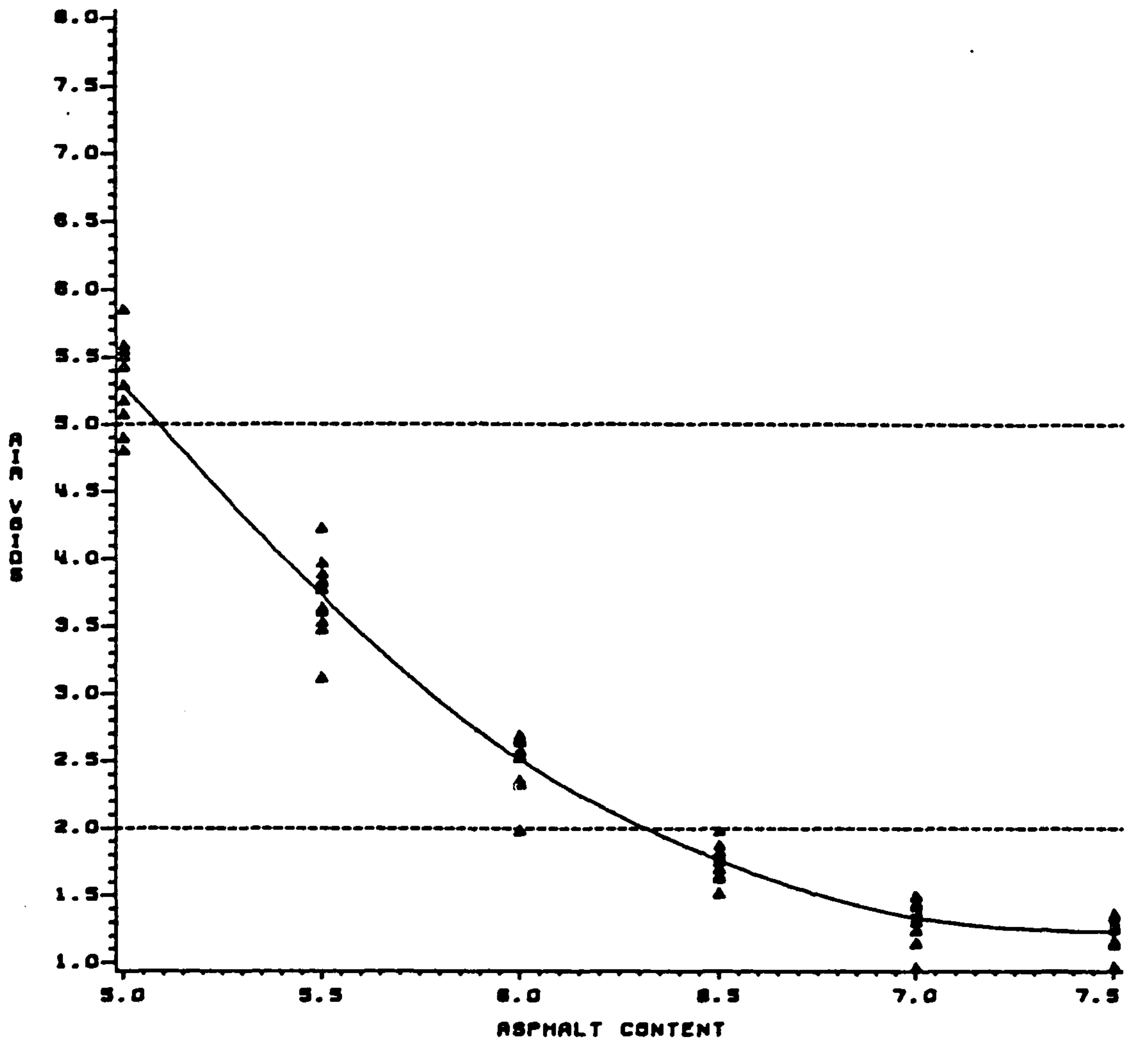


Figure 28. Air Voids vs. Asphalt Content: FAA Upper Gradation

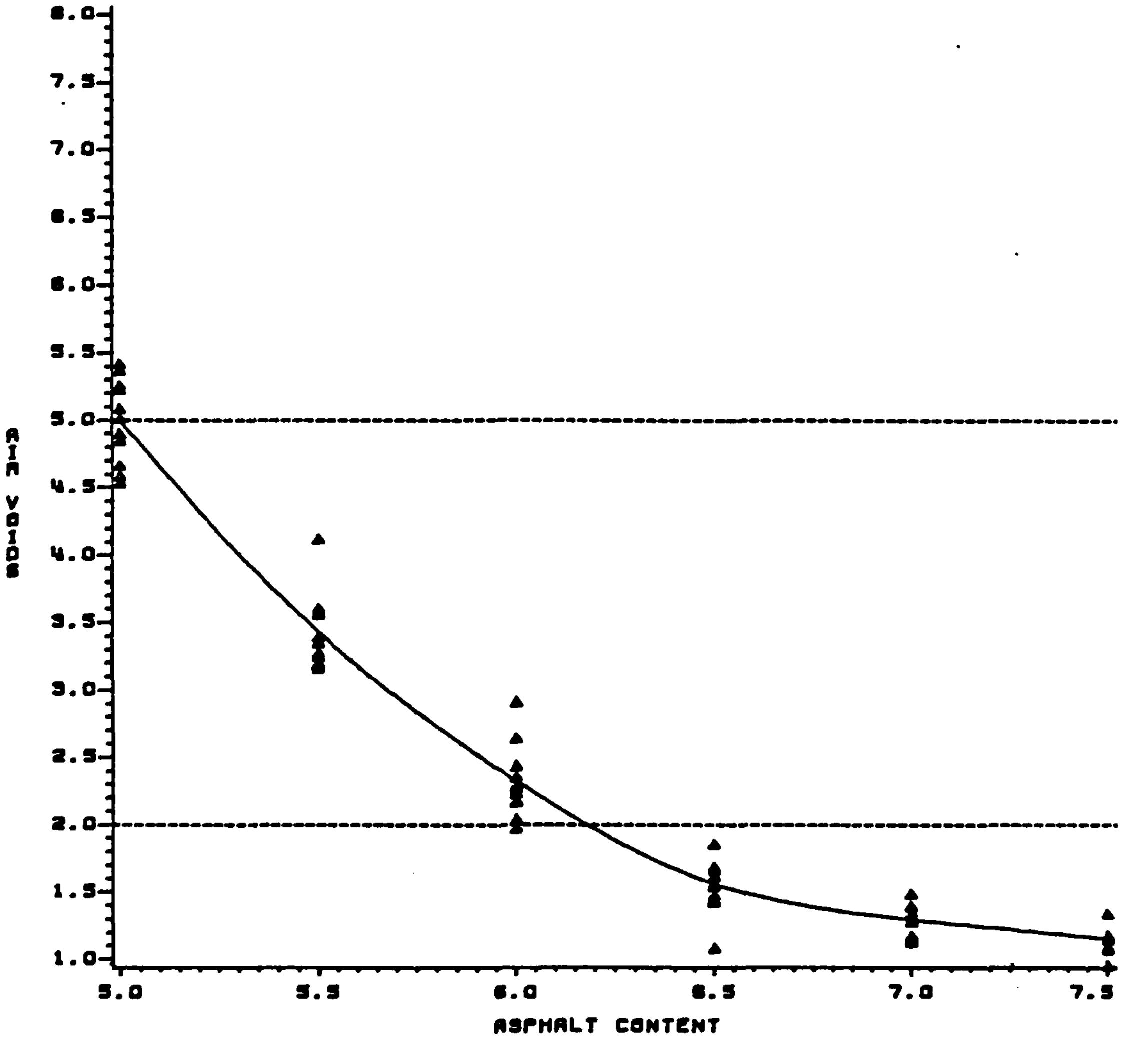


Figure 29. Air Voids vs. Asphalt Content: FAA Midpoint Gradation

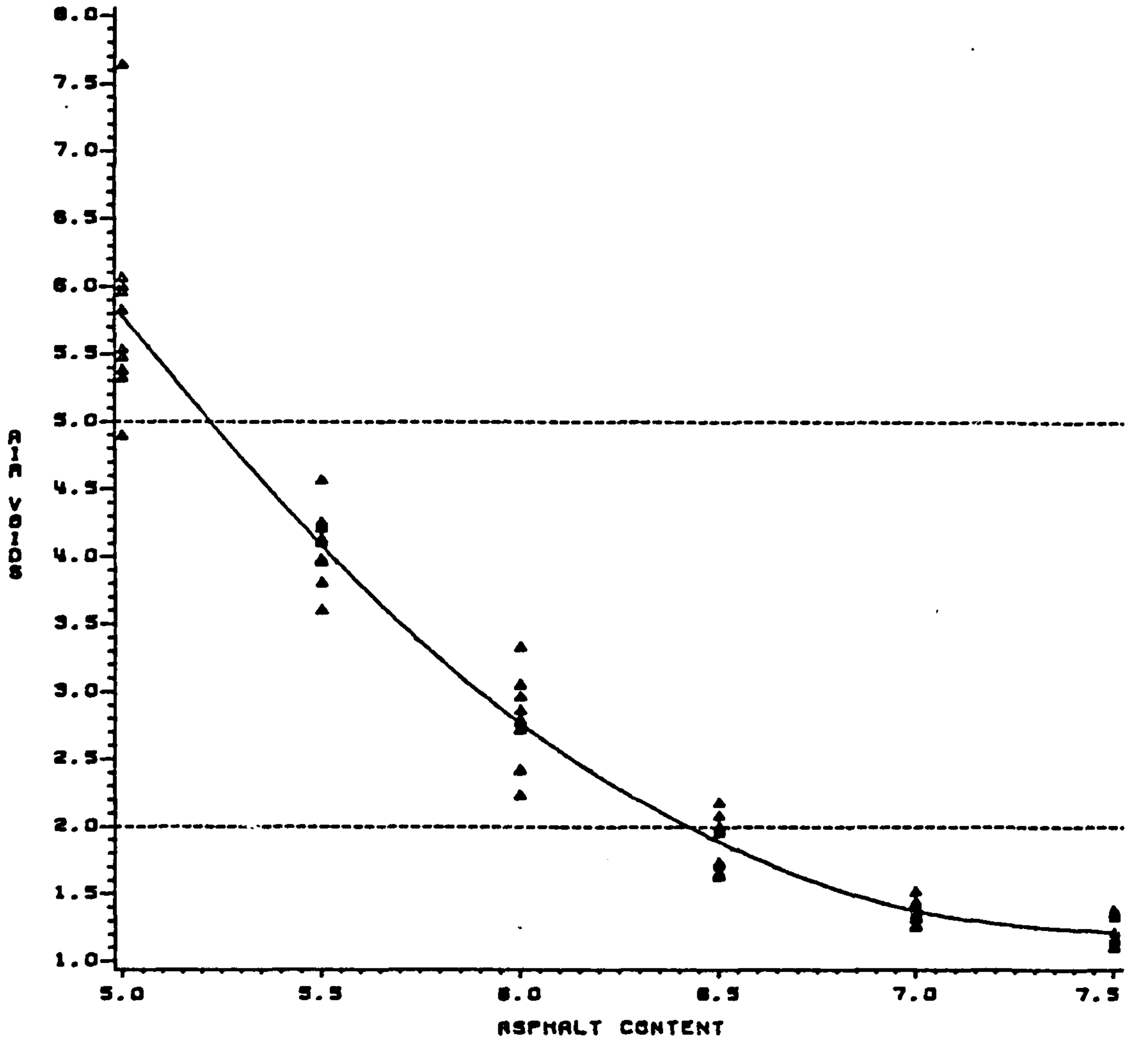


Figure 30. Air Voids vs. Asphalt Content: FAA Lower Gradation

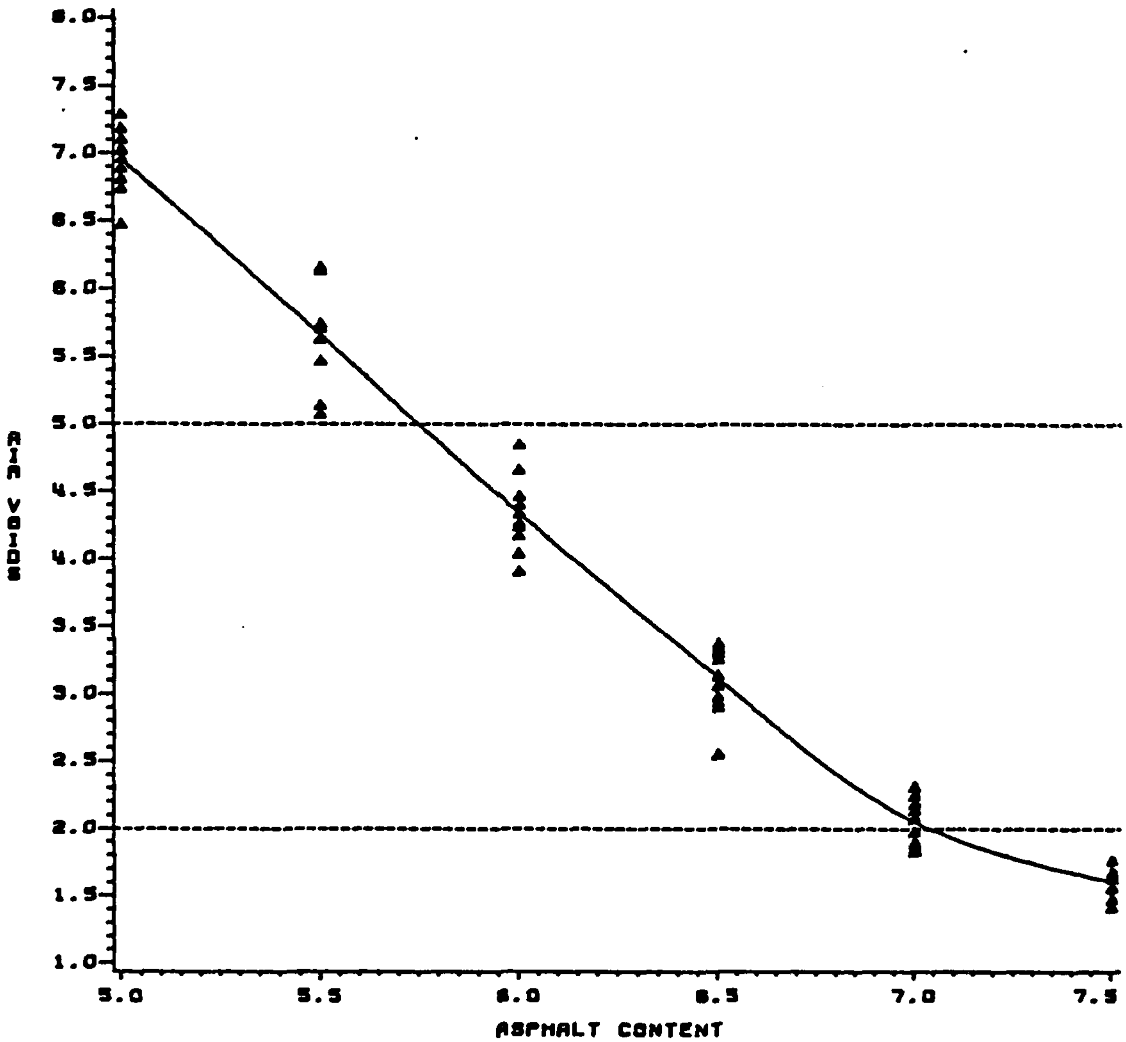


Figure 31. Air Voids vs. Asphalt Content: JMF Gradation

Standard Deviation versus Coefficient of Variation

It should be noted that when the coefficients of variation are compared, a similar increasing or decreasing trend with asphalt content is not apparent. This indicates that the trends in standard deviation are associated with corresponding increases or decreases in the mean values of the results as asphalt content increases. The coefficients of variation for stability, flow, and air voids appear in Appendices E, F, and G, respectively.

Optimum Asphalt Content Determination

The ERLPM and MS-2 determine the optimum percent asphalt content differently. The MS-2 manual specifies the optimum asphalt content as the average of the asphalt contents at the maximum stability, maximum unit weight, and the midpoint of the air voids specification limits. The percent air voids specification limits are 3-5 in MS-2 and 2-5 in the ERLPM. The ERLPM determines the optimum asphalt content using only the asphalt content at the midpoint of the air voids specification limits. The optimum asphalt contents were determined for each gradation in accordance with the ERLPM procedures and are presented in Table VII.

The Marshall properties are related to the optimum asphalt content for each gradation. The stability values in Figures 20-23, have a tendency to reach maximum values within approximately 1/2 percent asphalt content of the ERLPM optimum. This maximum stability and subsequent decrease is due to the aggregate particles becoming coated with a thicker film of asphalt cement as the asphalt content is increased. The asphalt cement is used in bituminous mixtures primarily to provide durability and act as a binder between aggregate particles. The asphalt cement alone cannot provide stability. As the asphalt film gets thicker, the aggregate particles tend to slip. If the asphalt content is increased to percentages well above the optimum, the air voids decrease. As a result, the aggregate becomes suspended in the asphalt cement and the ability to sustain applied loads is reduced. Similarly, at asphalt contents above optimum, the flow (Figures 24-27) rises sharply and air voids (Figures 28-31) decrease to a minimum.

Correlation Results

The results from the correlation analysis were investigated from both a generalized and detailed perspective that included each gradation and asphalt content. The correlations between stability and air voids, stability and flow, and flow and air voids were analyzed. The results from the analysis, which are based on 9 replicates (4 through 12), are plotted in Figures 32-35 and 44-45. The Upper, Midpoint, Lower, and JMF plots represent the correlation coefficients for the FAA Upper, FAA Midpoint, FAA Lower, and Rochester job mix formula gradations, respectively. The correlation coefficients can range from a perfect negative correlation of -1.0 to a perfect positive correlation of +1.0. The horizontal reference lines at +/- 0.67 for each correlation plot correspond to the 95% confidence limits for the null hypothesis that the true correlation coefficient is zero.

Table VII. Optimum Asphalt Contents in Accordance with the ERLPM for Gradations Used

Gradation	Optimum Asphalt Content (percent)
FAAU	5.6
FAAM	5.5
FAAL	5.7
JMF	6.3

As mentioned in the previous section, the Marshall properties are related to the optimum asphalt content for each gradation. Furthermore, it can be expected that the correlation coefficients among the properties may also be related to the optimum asphalt content for each gradation. There is a large difference between the gradation with the lowest optimum asphalt content (FAAM with 5.5%), and the gradation with the highest optimum asphalt content (JMF with 6.3%). Due to the differences in the optimum asphalt contents and the effect the optimum asphalt content for a particular gradation has on the Marshall properties, each gradation was adjusted for its respective optimum asphalt content to compare the correlations from each gradation. It was felt that the true relationship among the properties would not be revealed from correlation plots with the gradations not adjusted for their respective optimum asphalt contents. Therefore, the correlation coefficient plots without the gradations adjusted for their respective optimum asphalt content are not discussed, but are included for the reader's reference, (Figures 33, 35, 38, 40, 42, and 44).

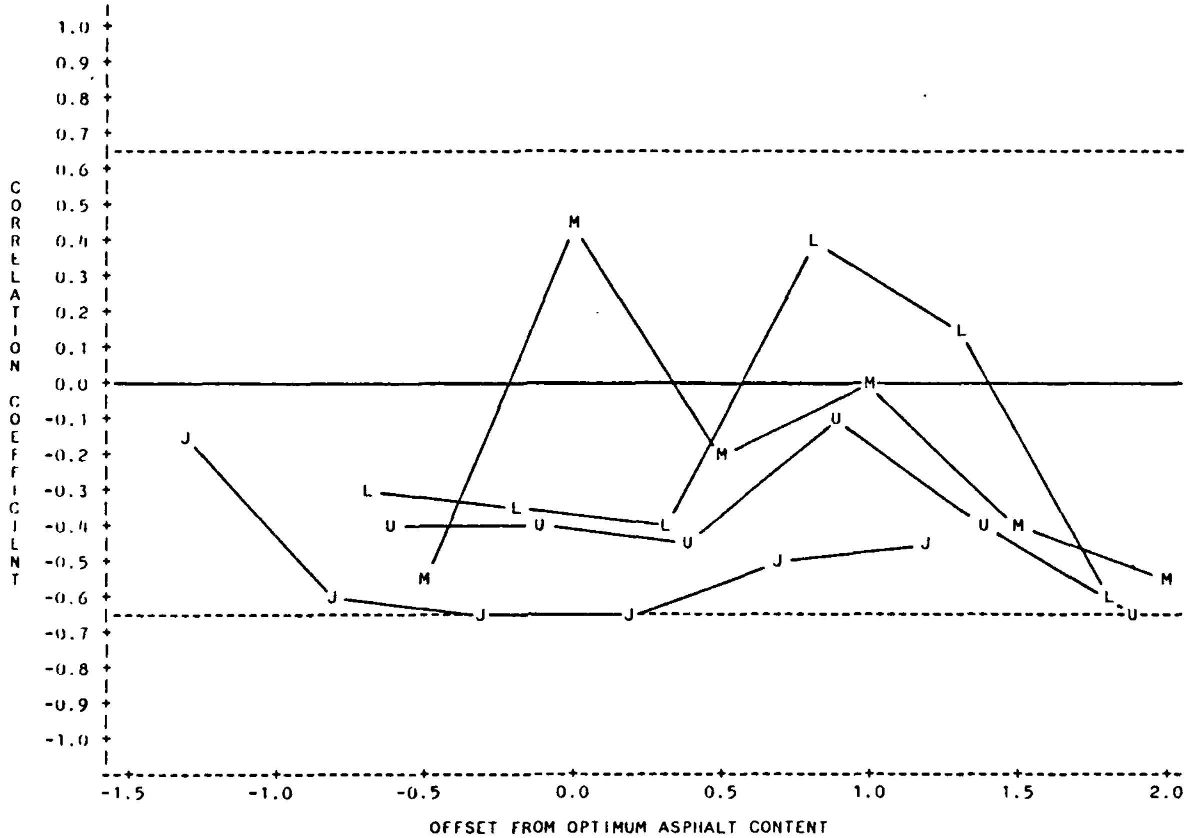
Although the correlation coefficients are not impressively large, consistent patterns among the results lead to speculation about the true relationships among the properties. Coefficients in this research effort ranging from approximately 0.3 to 0.4 were considered to be slightly or mildly correlated, coefficients ranging from 0.4 to 0.7 were considered moderately correlated, and significant correlations between 2 properties were considered to exist for coefficients of approximately 0.7 or higher.

<u>Stability and Air Voids Correlation Results</u>

A general analysis of the stability and air voids correlations reveals a low to moderately low negative correlation for all gradations at asphalt contents around optimum and below (Figure 32). At asphalt contents between 0.5% and 1.5% above optimum, the correlation coefficients are dependent upon the gradation. For greater than 1.5% above optimum asphalt content there is a low to moderate negative correlation. However, the asphalt cement is speculated to be controlling the properties at asphalt contents more than 1.5% above optimum.

To obtain these general conclusions, each gradation was analyzed individually. Referring to Figure 32, the Lower and Upper gradations are both mildly negatively correlated up to approximately 0.5% above the optimum asphalt content. At this point, the Lower gradation correlation becomes positively correlated and then reverts back to a negative correlation at 1.5% above optimum asphalt content. Although the Upper gradation follows the same pattern as the Lower gradation, the correlation coefficient at approximately 1.0% above optimum asphalt content does not become positive.

The Midpoint gradation, with the exception of the correlation coefficient at optimum asphalt content, also follows the same general pattern established by the Lower and Upper gradation correlation coefficients. The exact reason for a positive correlation at the optimum asphalt content is unknown. But, due to natural variaton in the



LEGEND: GRADATION J = JMF L = LOWER
M = MIDPOINT U = UPPER

NOTE: Dashed lines are 95% confidence limits for the hypothesis that the correlation coefficient, $\rho = 0$.

Figure 32. Stability vs. Air Voids Correlation Coefficient Plots Using Replicates 4-12 with Gradations Adjusted for Optimum Asphalt Content

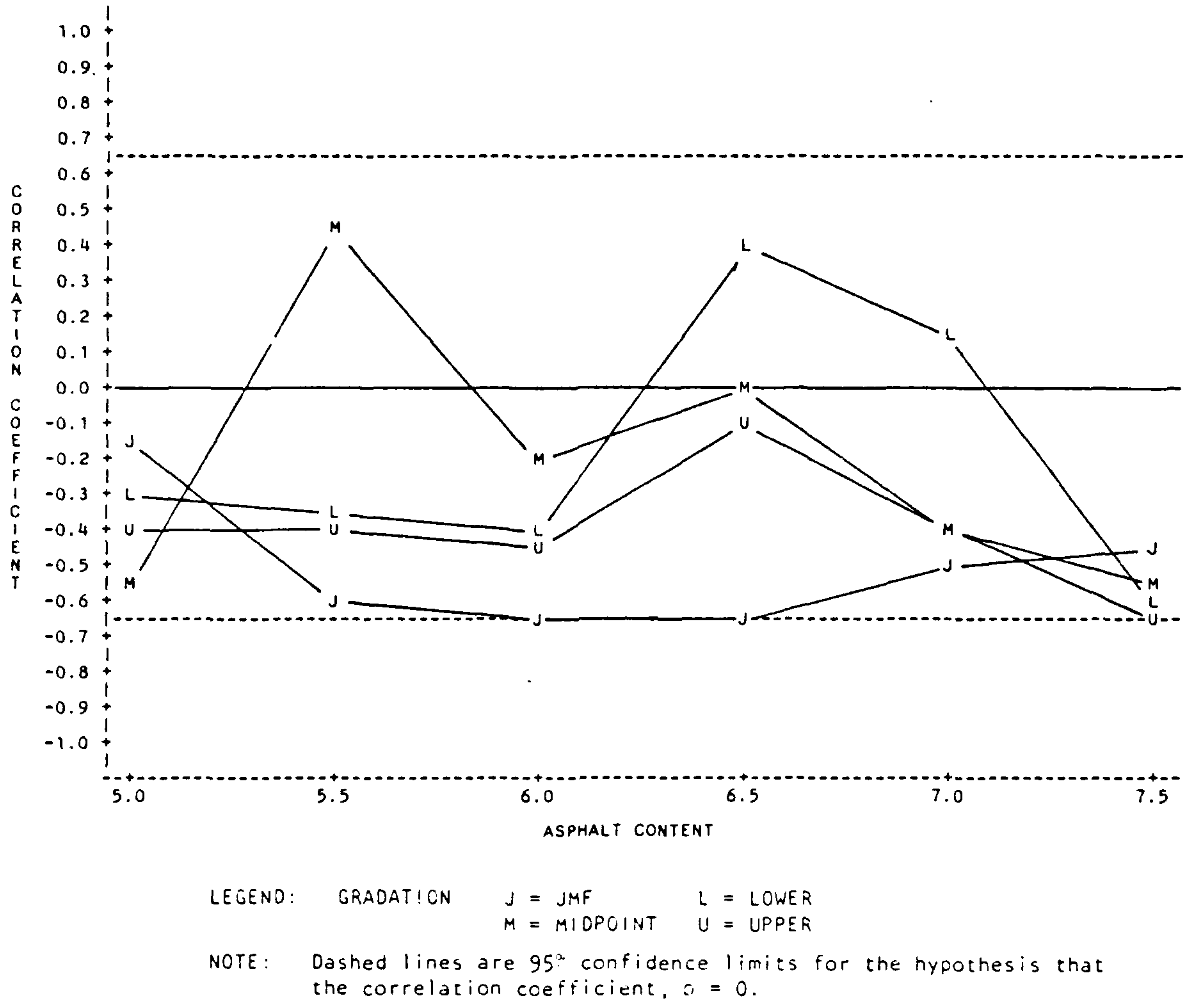


Figure 33. Stability vs. Air Voids Correlation Coefficient Plots Using Replicates 4-12

data, there is a chance of the data showing a positive correlation coefficient even if there is really a negative correlaton between stability and flow. Since the other three gradations show a consistent negative correlation, in addition to the negative coefficients at 0.5% below and 0.5% above optimum asphalt contents for the Midpoint gradation, it is believed that there is a negative correlation between stability and flow around optimum asphalt content and below, and that the positive coefficient at optimum asphalt content is simply due to natural variation in the data.

For the JMF gradation correlations in Figure 32, from approximately 0.5% asphalt content below optimum to 0.5% asphalt content above optimum, the same pattern established by the Lower and Upper gradations is apparent. The negative correlation in this range increases in magnitude slightly, and at asphalt contents higher than 0.5% above optimum, the correlation coefficient decreases.

It should be noted that due to the high optimum asphalt content of the JMF gradation, the lowest asphalt content tested (5.0%) for the JMF correlation coefficient stands alone when plotted with the other gradations adjusted for their respective optimum asphalt contents. What the Lower, Midpoint, and Upper gradation coefficients would be at asphalt contents 1.0% below the optimum cannot be extrapolated from the available data. In Figure 32, the JMF gradation could indicate there is not a correlation between stability and air voids at asphalt contents extremely below the optimum, which is what would be expected if there was an insufficient amount of asphalt cement in the mix to bind the aggregate particles together. However, it is difficult to make a positive statement on the correlation based on a single correlation coefficient from only 9 replicates.

In practice, the production of asphalt concrete at the plant should not vary as much as 1.0% above or below the optimum asphalt content. Since the main concern of the research is the relationship among the properties at asphalt contents encountered in asphalt concrete mixtures in the field, the correlation coefficient for the JMF more than 1.0% below optimum is not significant to the overall results of the correlation analysis.

The moderately low correlation coefficient for each gradation would not have significance if viewed individually, but, with all of the gradations taken as a whole, the final conclusion is that a moderately low negative correlation between stability and air voids exists from below to slightly above optimum asphalt contents. If there was not a correlation between stability and air voids, ideally, each of the gradations should show erratic correlation patterns averaging about the zero correlation coefficient.

Stability and Flow Correlation Results

An initial analysis of the 4 gradations for Marshall stability and flow correlations revealed a slight positive correlation at and below approximately 0.5% above the optimum asphalt content. From 0.5% to 1.5% above the optimum, the correlations appear to be dependent upon the

gradation (Figure 34). At more than 1.5% above optimum, the coefficients, on the average, form a slight positive correlation. However, as noted in the stability and air voids correlation results, the asphalt cement is probably controlling the results of the mixture due to the high asphalt content.

Referring to Figure 34 that presents the stability and flow correlation coefficients for each gradation adjusted for its respective optimum asphalt content, the JMF and Upper gradations correlation coefficients, although not consistent in any pattern, tend to average about a zero correlation coefficient. At 1.0% below optimum asphalt content the JMF gradation correlation coefficient is essentially zero. It increases to a mild positive correlation slightly below the optimum asphalt content before becoming a small negative correlation at approximately 0.5% above optimum. The correlation is then positive at more than 1.0% above the optimum asphalt content.

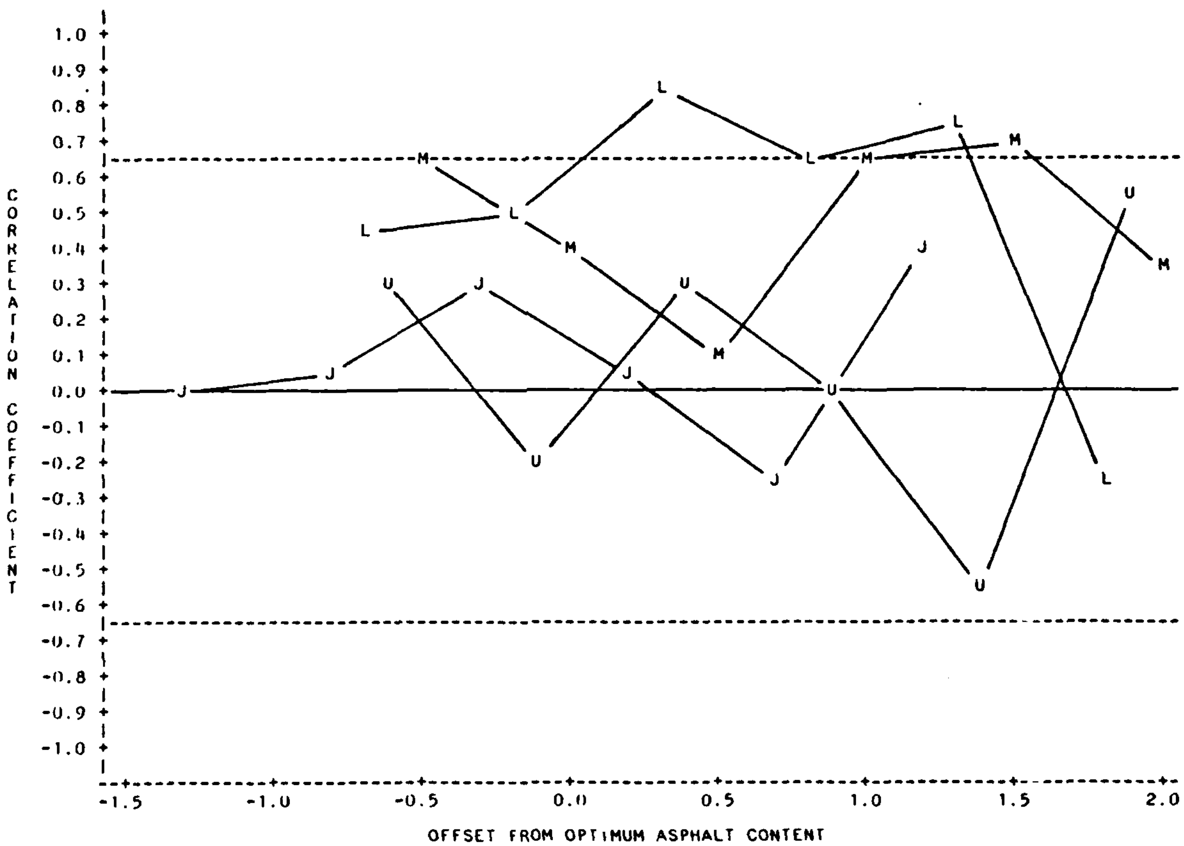
The Upper gradation is mildly positively correlated at about 0.5% below optimum and, as asphalt content increases, becomes a negative correlation before starting a cycle in which the correlation coefficient becomes negative and then reverts back to positive. Because these correlations tend to average about the zero correlation coefficient, the correlation between stability and flow for these 2 gradations was first thought to be zero. But, as will be shown later in this section, the correlations are now believed to be slightly positive.

The Lower and Midpoint gradations in Figure 34, with the exception of the Midpoint correlation coefficient at 0.5% above optimum asphalt content, form a pattern. From approximately 0.5% below optimum to slightly more than 1.0% above optimum asphalt content, the correlation coefficients are moderately positive with the exception noted above. As discussed previously, at 1.5% above optimum asphalt content and greater, the asphalt cement is speculated to control the Marshall properties.

The correlations appear to be dependent upon the gradation, and if all of the correlation coefficients are considered as a whole, the result is a weak positive correlation. But, a detailed analysis of the stability and flow correlations revealed an outlier in the scatter plots of stability versus flow that significantly influences the results of the correlation coefficients. The outlier, as shown in Figure 36, in the 5.5% asphalt content Upper gradation scatter plot, causes the correlation coefficient to be -0.223. If the outlier is deleted, the coefficient becomes +0.382.

If the outlier is deleted and the new correlation coefficients plotted (Figure 37), a moderately low positive correlation between stability and flow, on the average, becomes apparent around 0.5% above optimum asphalt content and below. From around 0.5% above optimum asphalt content to aproximately 1.5% above optimum asphalt content, the correlations appear to be dependent upon the gradation. The Lower and Midpoint correlation coefficients are significantly positive, whereas the JMF correlation goes from a slight positive correlation coefficient to a moderate negative correlation coefficient.

The other correlations were also influenced by the deletion of the outlier. The stability and air voids correlation coefficient for the Upper gradation at 5.5% asphalt content changed from -0.396 to -0.722. There was a slight decrease, from -0.308 to -0.151, in the Upper gradation at 5.5% asphalt content for the flow and air voids correlations. The stability and air voids and flow and air voids correlation plots without the outlier are shown in Figures 39-42, respectively. The purpose of deleting the observation was to show how much influence one outlier can have on a correlation coefficient and to show that a moderately low positive correlation probably does exist between stability and flow.



LEGEND: GRADATION J = JMF L = LOWER
M = MIDPOINT U = UPPER

NOTE: Dashed lines are 95% confidence limits for the hypothesis that the correlation coefficient, ρ = 0.

Figure 34. Stability vs. Flow Correlation Coefficient Plots Using Replicates 4-12 with Gradations Adjusted for Optimum Asphalt Content

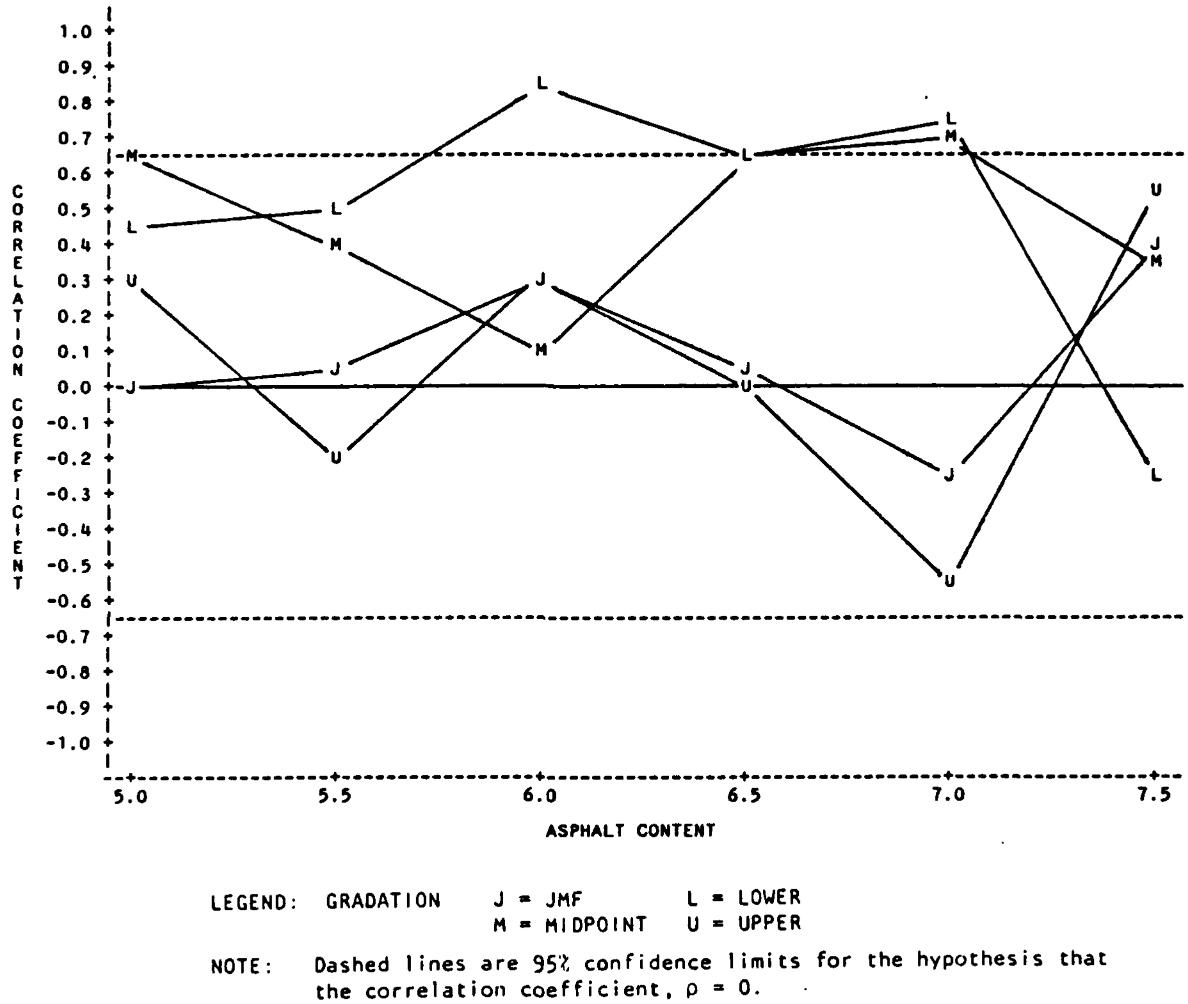


Figure 35. Stability vs. Flow Correlation Coefficient Plots Using Replicates 4-12

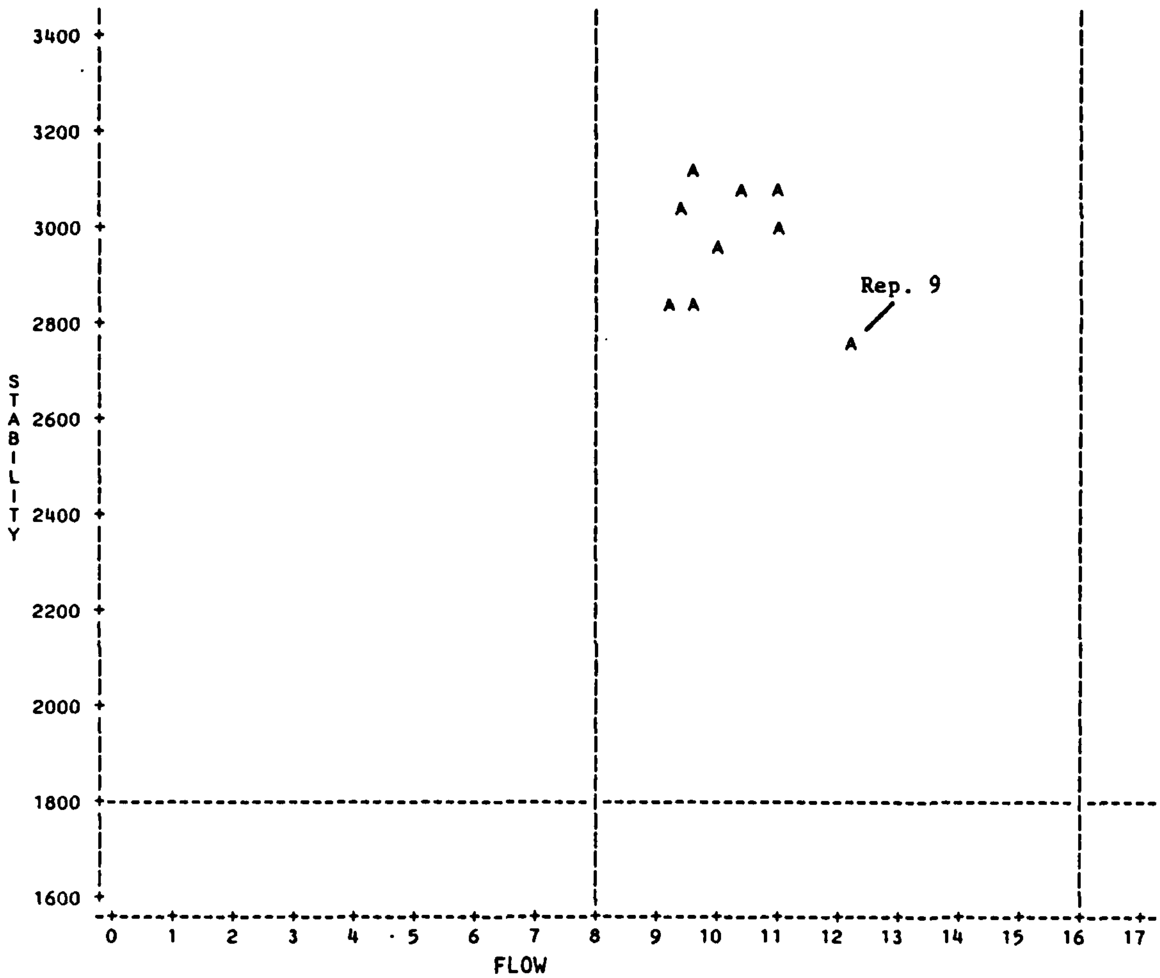
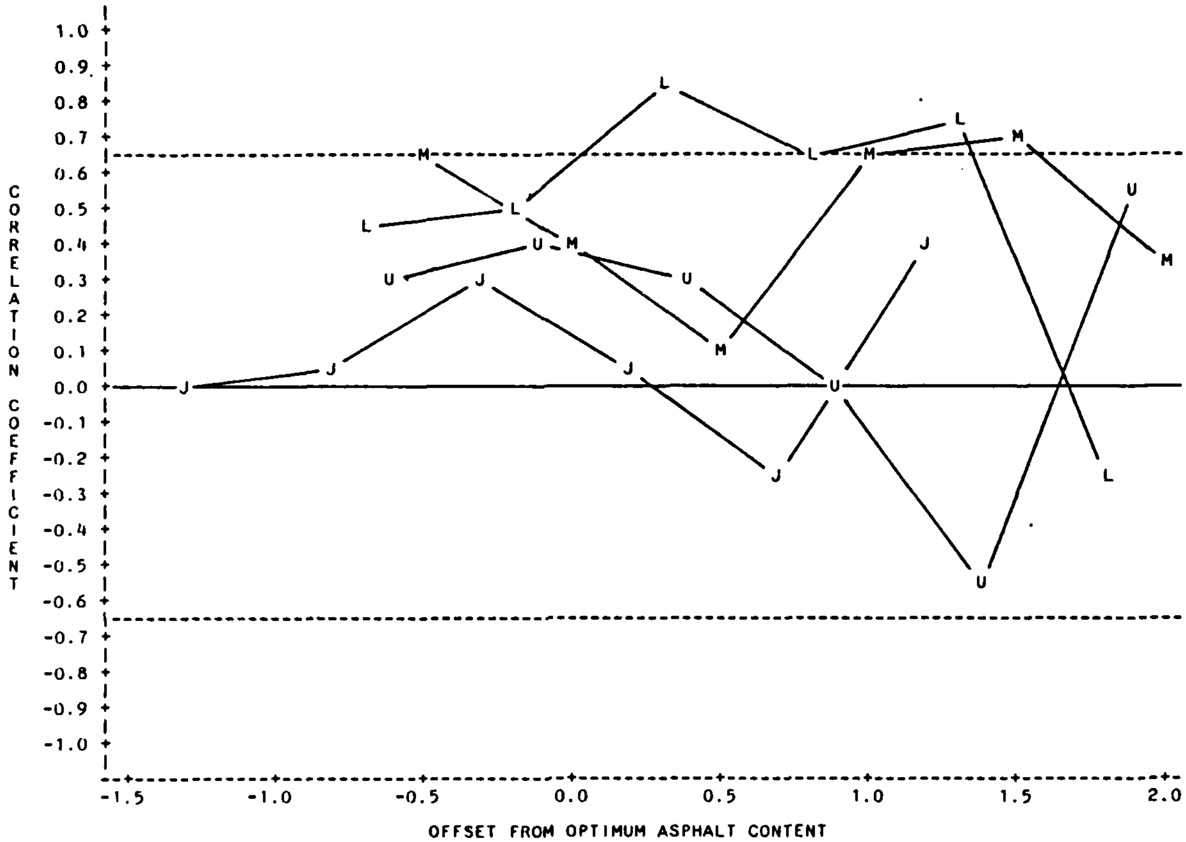


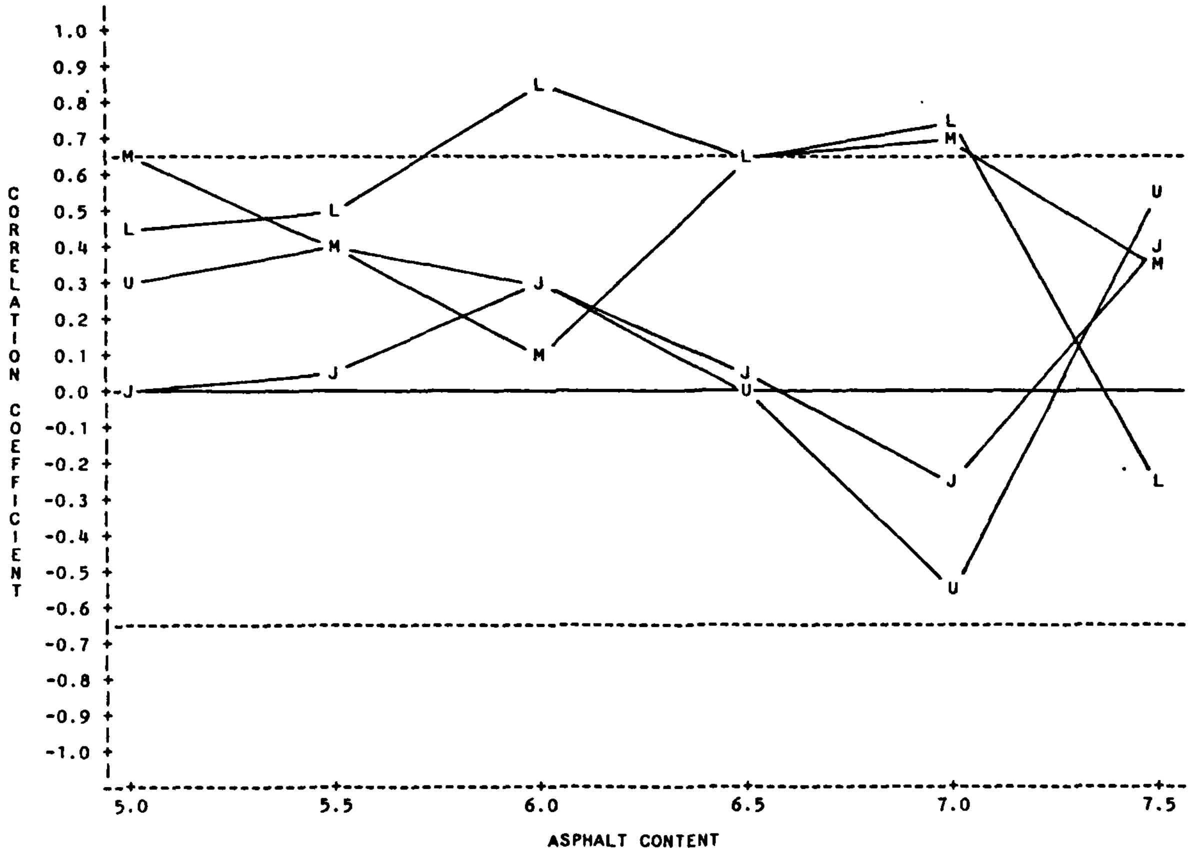
Figure 36. Stability vs. Flow Scatter Plot for the FAA Upper Gradation at 5.5% Asphalt Content



LEGEND: GRADATION J = JMF L = LOWER
M = MIDPOINT U = UPPER

NOTE: Dashed lines are 95% confidence limits for the hypothesis that the correlation coefficient, $\rho = 0$.

Figure 37. Stability vs. Flow Correlation Coefficient Plots Using Replicates 4-12 Less Outlier with Gradations Adjusted for Optimum Asphalt Content



LEGEND: GRADATION J = JMF L = LOWER
M = MIDPOINT U = UPPER

NOTE: Dashed lines are 95% confidence limits for the hypothesis that the correlation coefficient, ρ = 0.

Figure 38. Stability vs. Flow Correlation Coefficient Plots Using Replicates 4-12 Less Outlier

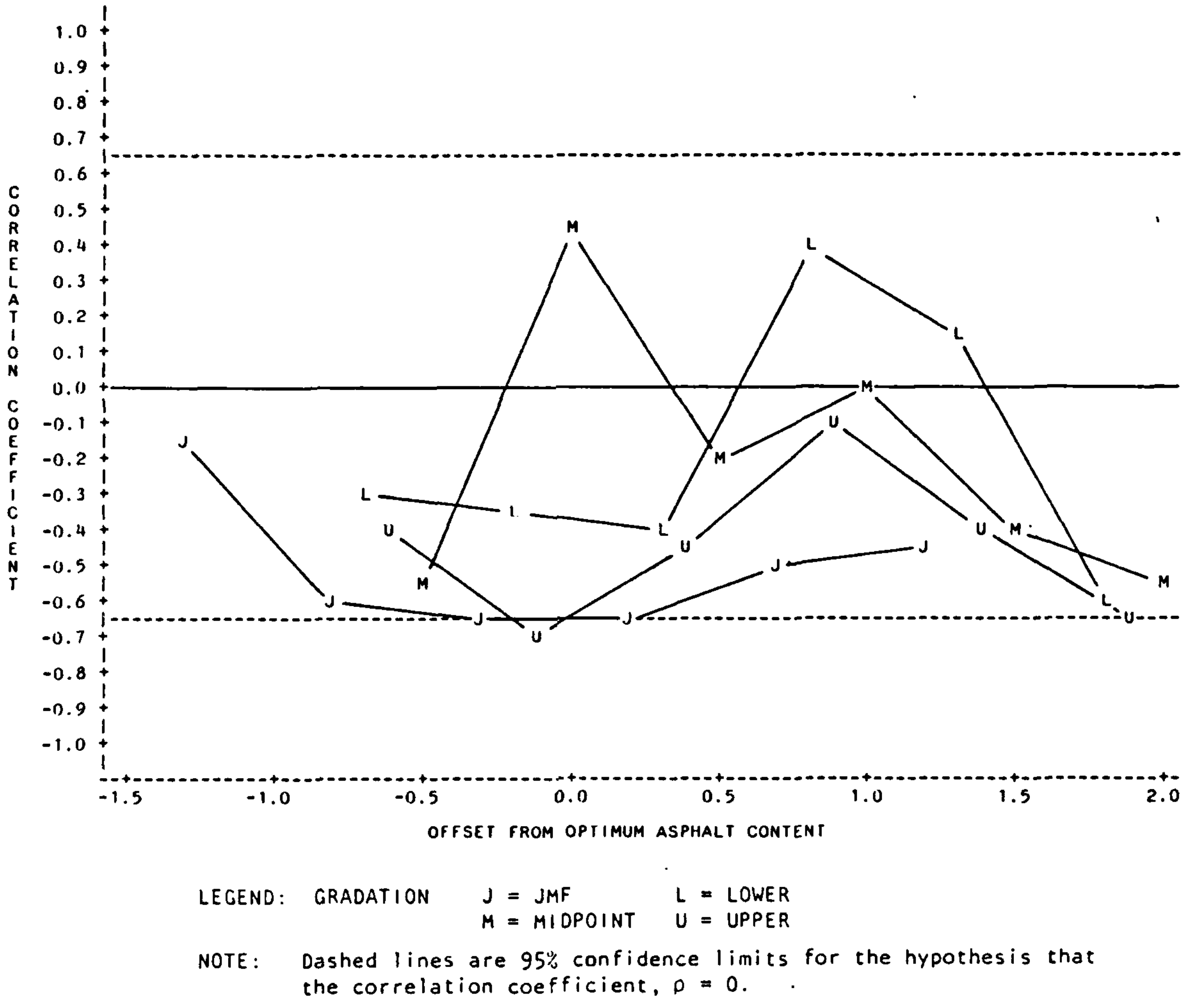
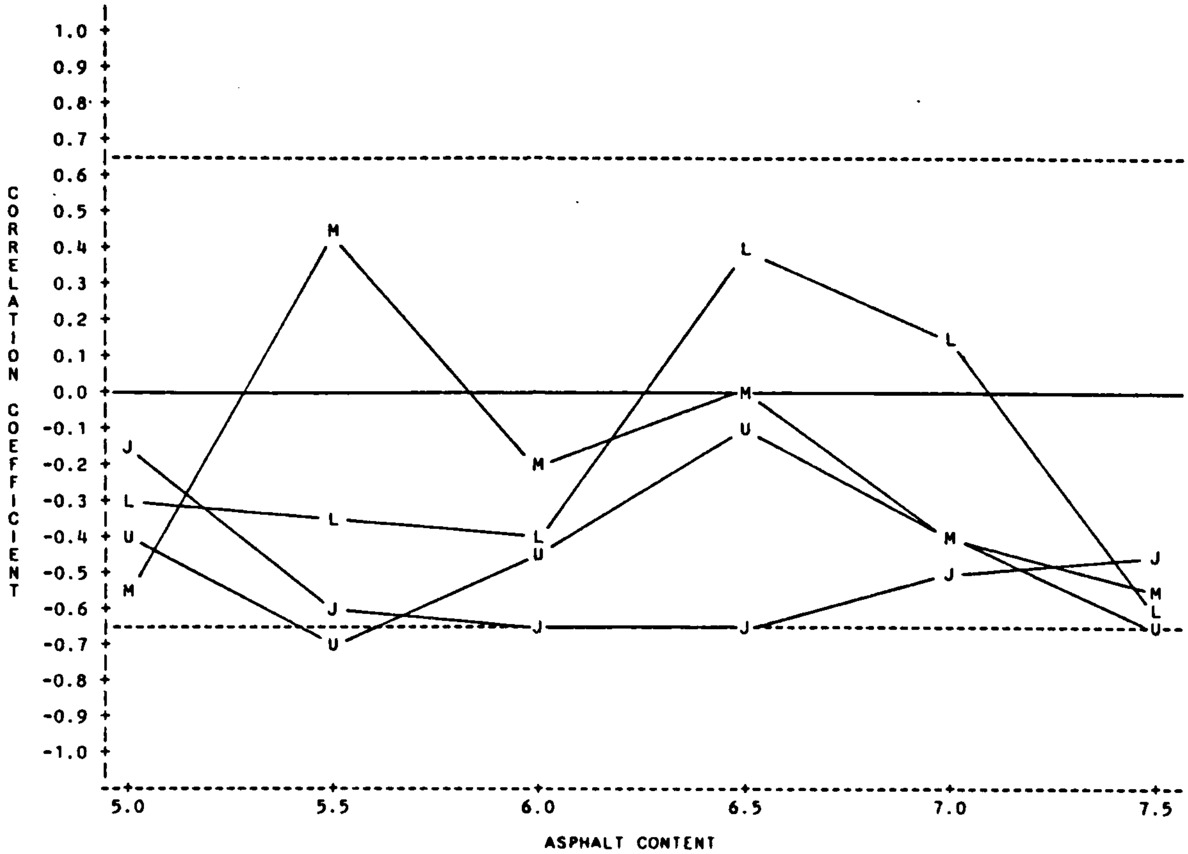


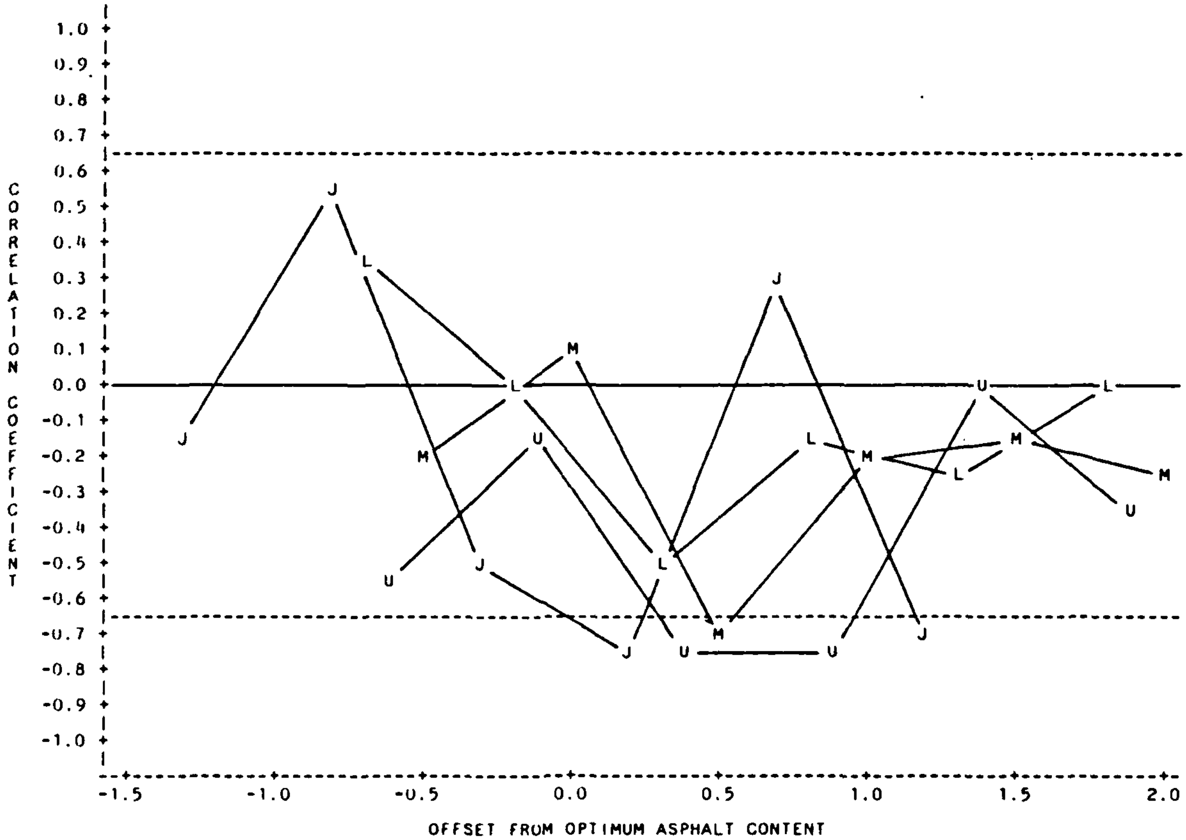
Figure 39. Stability vs. Air Voids Correlation Coefficient Plots Using Replicates 4-12 Less Outlier with Gradations Adjusted for Optimum Asphalt Content



LEGEND: GRADATION J = JMF L = LOWER
M = MIDPOINT U = UPPER

NOTE: Dashed lines are 95% confidence limits for the hypothesis that the correlation coefficient, $\rho = 0$.

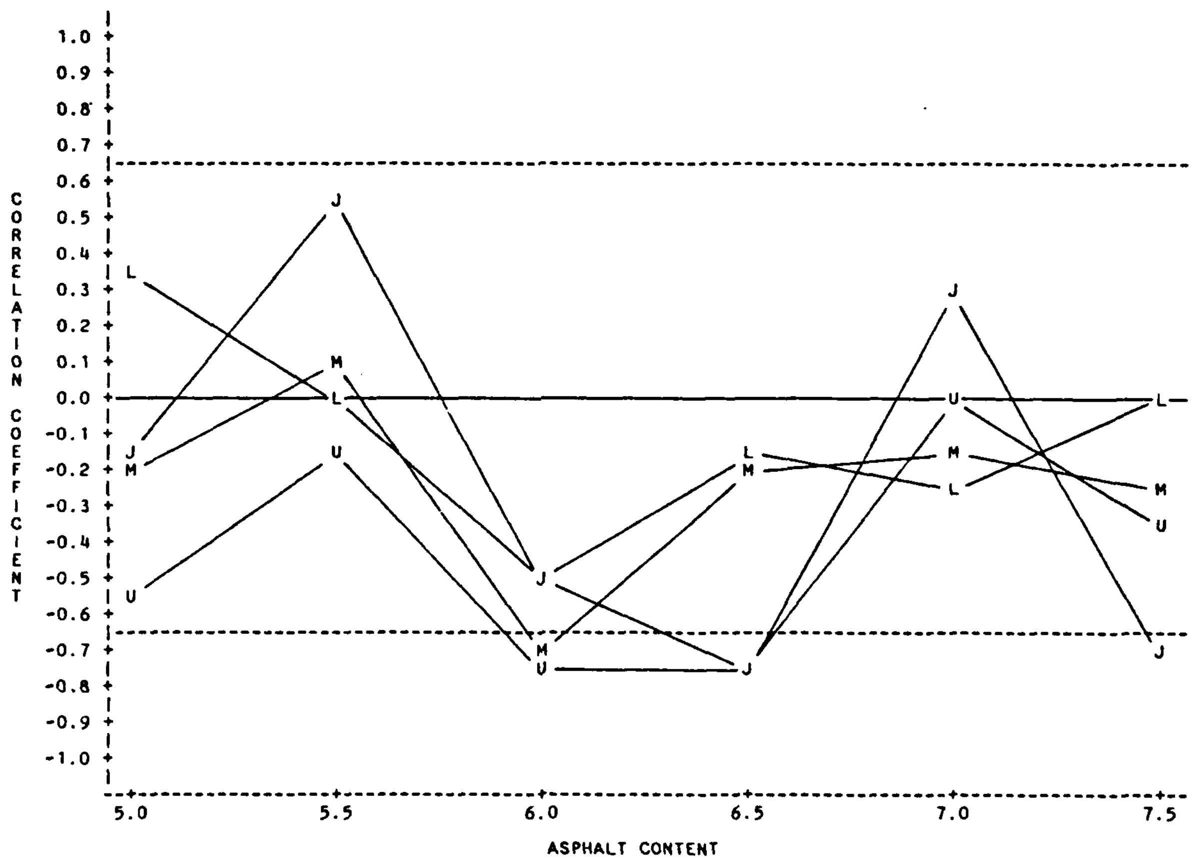
Figure 40. Stability vs. Air Voids Correlation Coefficient Plots Using Replicates 4-12 Less Outlier



LEGEND: GRADATION J = JMF L = LOWER
M = MIDPOINT U = UPPER

NOTE: Dashed lines are 95% confidence limits for the hypothesis that the correlation coefficient, ρ = 0.

Figure 41. Flow vs. Air Voids Correlation Coefficient Plots Using Replicates 4-12 Less Outlier with Gradations Adjusted for Optimum Asphalt Content



LEGEND: GRADATION J = JMF L = LOWER
M = MIDPOINT U = UPPER

NOTE: Dashed lines are 95% confidence limits for the hypothesis that the correlation coefficient, $\rho = 0$.

Figure 42. Flow vs. Air Voids Correlation Coefficient Plots Using Replicates 4-12 Less Outlier

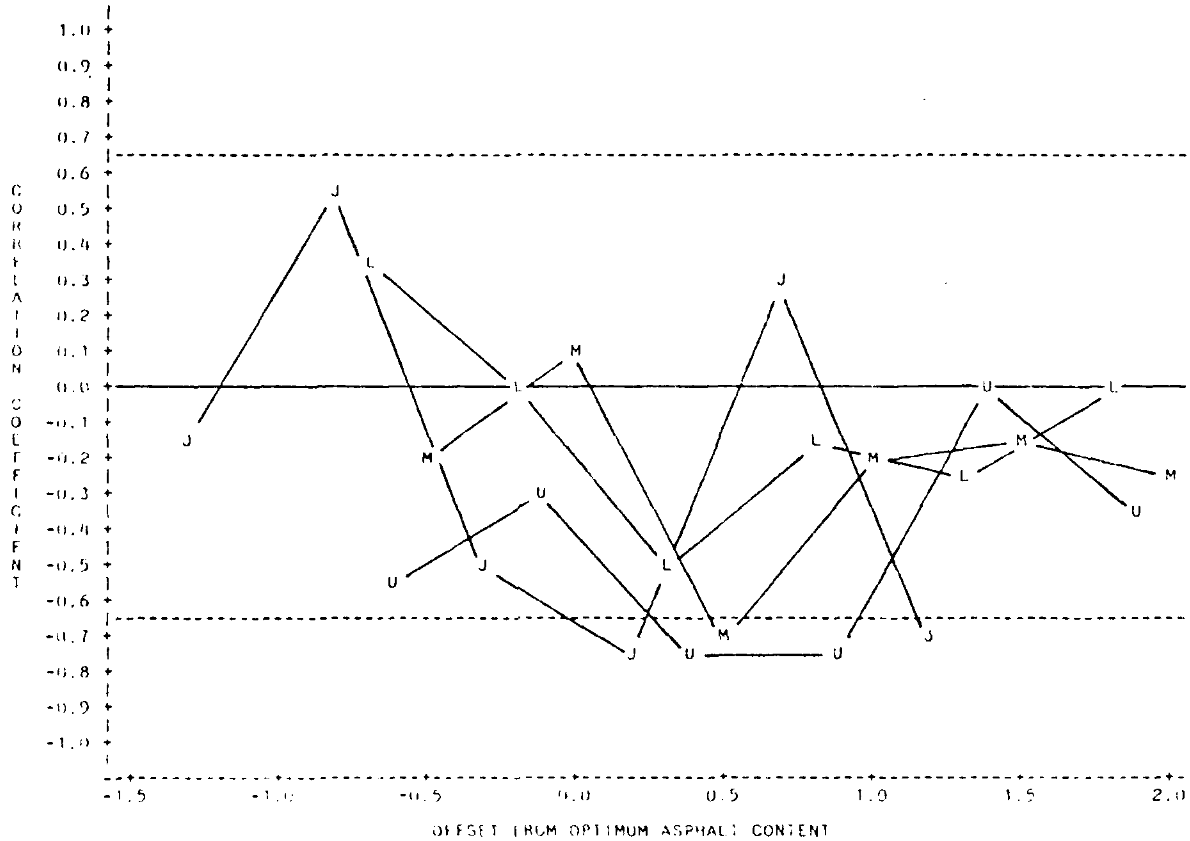
Flow and Air Voids Correlation Results

The last correlation analysis considered was between flow and the percent air voids in the total mix. From a general analysis of the 4 gradation correlation coefficients, there appears to be, on the average, a mild negative correlation between flow and air voids at optimum asphalt content and above. As shown in Figure 43, from approximately 1.0% below optimum asphalt content to around 0.5% above optimum, the general trend is an increasing negative correlation. At asphalt contents greater than 0.5% above optimum asphalt content, the trend is for the correlation coefficients, on the average, to decrease.

The 4 gradations follow a similar correlation pattern throughout the asphalt content range. The JMF correlation more than 1.0% below optimum asphalt content is negative (Figure 43). The correlation between 2 properties based on only 1 correlation coefficient is difficult to determine. But, at asphalt contents far below the optimum, the correlation in probably zero due to the small amount of asphalt cement in the mixture. From approximately 1.0% below optimum asphalt content to slightly above optimum asphalt content, the JMF correlation switches from a moderate positive coefficient to a significant negative coefficiet. At approximately 0.5% above optimum asphalt content, the correlation coefficient becomes mildly positive, but around 1.0% above optimum asphalt content, the correlation reverts back to a moderate negative correlation coefficient. Since the correlation coefficients above and below the coefficient at approximately 0.5% above optimum are either moderate or significantly negative, and the other 3 gradations in the same range also show a negative correlation, it is believed the positive correlation coefficient for the JMF is due to the natural variability in the data. The true correlation is probably negative, despite the positive value for this sample.

The Lower, Midpoint, and Upper correlations form a very consistent pattern. Although the Lower coefficient is mildly positive, and the Midpoint and Upper coefficients are slightly and moderately negatively correlated around 0.5% below optimum asphalt content, respectively (Figure 44), all 3 correlation coefficients decrease in magnitude at optimum asphalt content. The correlation coefficients increase to moderate to significant levels at 0.5% above optimum before again decreasing in magnitude to slight, but negative, correlation coefficients from 1.0% to 1.5% above optimum asphalt content. As noted above, at asphalt contents around 1.5% above optimum asphalt content and above, the asphalt cement is probably controlling the results of the Marshall properties.

The erratic nature of the correlation patterns for each gradation provides little information on the true relationship between flow and air voids if viewed individually. However, with all of the gradations taken as a whole, the final conclusion is that there is a mild negative correlation between the properties at optimum asphalt content and above.



LEGEND: GRADATION J = JMF L = LOWER
M = MIDPOINT U = UPPER

NOTE: Dashed lines are 95% confidence limits for the hypothesis that the correlation coefficient, ρ = 0.

Figure 43. Flow vs. Air Voids Correlation Coefficient Plots Using Replicates 4-12 with Gradations Adjusted for Optimum Asphalt Content

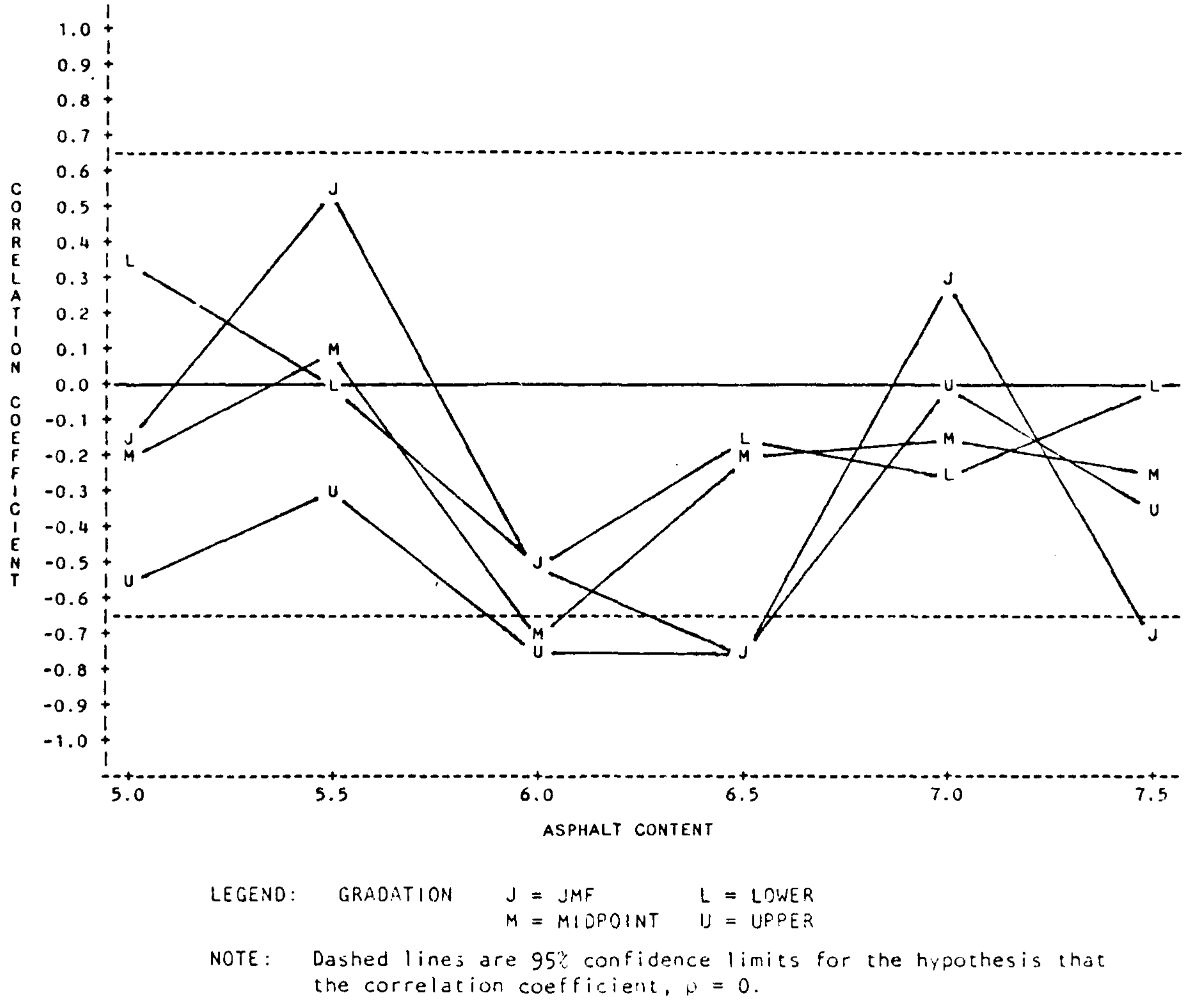


Figure 44. Flow vs. Air Voids Correlation Coefficient Plots Using Replicates 4-12

CHAPTER V

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

This research effort is the laboratory phase of a 3-phase research project for the Federal Aviation Administration. The research was conducted to evaluate the possibility of implementing a multiple price adjustment system for bituminous airport pavements using the Marshall properties: stability, flow, and air voids. The Marshall properties are physically related, i.e., determined from a single test, and, therefore, can be expected to be statistically correlated. To use these properties in a multiple price adjustment system, the correlations among the properties needed to be identified. This research effort was designed to identify such correlations.

The experimental design consisted of 4 aggregate gradations spanning the FAA Eastern Region specification limits for loads greater than 60,000 pounds and maximum 3/4-inch stone, and 6 asphalt contents from 5.0% to 7.5% at 0.5% increments, for a total of 24 different combinations for 1 replicate. Twelve replicates were made for a total of 288 Marshall briquets. Each replicate was mixed on one day and tested on the next. Other than asphalt content and aggregate gradation, factors influencing the Marshall test results were held to a minimum. The aggregate was crushed limestone and natural sand, and the asphalt cement was AC-20. The laboratory procedures followed were in accordance with those specified in the FAA Eastern Region Laboratory Procedures Manual (ERLPM) (9).

Several analyses were conducted on the data. An analysis of variance (ANOVA) and Duncan's Multiple Range test were performed on the data to determine whether time, i.e., order, had an effect on the test results. The Marshall properties were plotted against percent asphalt content, and the optimum asphalt content was determined for each gradation in accordance with the ERLPM. The Marshall property plots were also compared to accepted plots in the Asphalt Institute's Manual Series No. 2 (MS-2), Mix Design Methods for Asphalt Concrete. Correlation coefficients among the Marshall properties for each asphalt content/aggregate gradation combination were clculated using the Statistical Analysis System (SAS) computer program. The correlations were compared by plotting the correlation coefficients against the percent asphalt content with each gradation adjusted for its respective optimum asphalt content.

Conclusions

From the results of the Marshall property correlation analyses, the following conclusions were reached.

1. The data conform to the accepted correlation patterns among Marshall stability, flow, and air voids versus asphalt content.

2. The standard deviation for each Marshall property varies with regard to aggregate gradation and asphalt content. Generally, the standard deviations for stability and air voids decrease as percent asphalt content increases, and increase as percent asphalt content increases for flow.

3. There were no significant correlations among the Marshall properties. However, a moderately low negative correlation coefficient exists between stability and flow from below to approximately 0.5% above the optimum asphalt content. And, a mild negative correlation exists between flow and air voids at optimum asphalt content and above.

4. The correlations for stability and air voids, and stability and flow appear to be dependent upon the aggregate gradation from approximately 0.5% above optimum to approximately 1.5% above optimum asphalt contents.

5. There appears to be no correlation among the Marshall properties at more than 1.0% below the optimum asphalt content. But, due to the low optimum asphalt contents of the gradations chosen, and the range of the asphalt contents tested, only one gradation had a correlation coefficient more than 1.0% below the optimum asphalt content. This makes it difficult to make a positive statement on a correlation between two properties based on a single correlation coefficient.

6. The results of the correlation analysis are not significant enough to justify eliminating one or more of the Marshall properties from use in a multiple price adjustment system, but they appear to be significant enough to violate an assumption of statistical independence among the properties.

These conclusions are based on the asphalt cement, asphalt contents, aggregates, and aggregate gradations, considered in this investigation.

Recommendation

The results of the laboratory analysis indicate that it is not sufficent to consider the Marshall results to be statistically independent. This means that it is probably not appropriate to consider the properties separately and then to multiply the individual results to arrive at an acceptance decision for the Marshall properties. It is recommended that computer simulation analyses be conducted to investigate methods for treating the case of correlated multiple acceptance properties. The results of such analyses are presented in subsequent volumes of this report series.

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11. David, F. N., "Tables of the Ordinates and Probability Integral of Distribution of the Correlation Coefficient in Small Samples". Cambridge University Press, Cambridge, 1938.

APPENDICES

Appendix A

Example Maximum Theoretical Specific Gravity
Determination: FAA Lower Gradation 5.0%
Asphalt Content

Aggregate	% by Total Wgt	Sp Gr.
Coarse (-3/4, +No. 4)	38.95	2.700
Fine - Limestone (-No. 4, +Pan)	42.01	2.684
Fine - Nat. Sand (-No. 16, +Pan)	14.04	2.660
Asphalt Cement	5.0	1.020

Max. Theoretical Specific Gravity =

$$\frac{100\%}{\frac{38.95}{2.700} + \frac{42.01}{2.684} + \frac{14.04}{2.660} + \frac{5.00}{1.020}}$$

Max. Theoretical Specific Gravity = 2.484 (FAA Lower - 5.0% AC)

Appendix B

Marshall Properties and Related Laboratory Test Data

FAA BITUMINOUS CONCRETE TESTING REPORT

REPLICATE 1

SPEC-IMEN NO.	GRAD-ATION	ASPHALT CONTENT PERCENT	THICK-NESS INCHES	WGT----GRAMS IN AIR	IN WATER	SAT.SUR DRY	VOL. CC	SP. GRAVITY ACT.	THEO. GMM	VOID % TOTAL MIX	FILLED VF	UNIT WT TOT.MIX LB/CUFT	STABILITY-LB MEAS-URED	CONV-ERTED	FLOW UNITS OF 1/100 IN
8	FAAL	5.0	2.56	1211.3	694.1	1214.7	520.6	2.327	2.484	6.33	64.31	145.19	2490	2490	11.0
10	FAAL	5.5	2.56	1214.4	698.4	1216.4	518.0	2.344	2.465	4.89	72.10	146.29	2350	2350	10.2
2	FAAL	6.0	2.50	1219.1	708.3	1220.3	512.0	2.381	2.447	2.69	83.86	148.58	2890	2890	11.6
9	FAAL	6.5	2.53	1223.0	708.1	1224.3	516.2	2.369	2.429	2.46	85.99	147.84	2700	2700	13.6
18	FAAL	7.0	2.53	1230.0	713.2	1231.2	518.0	2.375	2.411	1.51	91.50	148.17	2170	2170	16.0
14	FAAL	7.5	2.56	1235.9	713.9	1237.2	523.3	2.362	2.394	1.35	92.80	147.37	2000	1920	18.6
4	FAAM	5.0	2.50	1211.7	695.6	1213.9	518.3	2.338	2.483	5.85	66.22	145.88	2760	2760	10.3
3	FAAM	5.5	2.50	1218.7	703.0	1220.1	517.1	2.357	2.464	4.35	74.50	147.06	2850	2850	11.5
17	FAAM	6.0	2.50	1228.4	715.5	1229.5	514.0	2.390	2.446	2.29	85.97	149.13	2790	2790	13.5
11	FAAM	6.5	2.53	1231.1	714.5	1232.2	517.7	2.378	2.428	2.06	88.04	148.39	2570	2570	16.3
24	FAAM	7.0	2.56	1230.5	713.8	1231.9	518.1	2.375	2.410	1.45	91.82	148.20	2380	2380	16.8
19	FAAM	7.5	2.56	1236.9	714.3	1237.9	523.6	2.362	2.393	1.28	93.12	147.41	1930	1853	22.9
21	FAAU	5.0	2.53	1213.1	698.6	1213.8	515.2	2.355	2.482	5.13	69.22	146.93	3300	3300	9.8
1	FAAU	5.5	2.50	1214.0	706.2	1215.1	508.9	2.386	2.464	3.18	80.16	148.86	3470	3470	12.2
7	FAAU	6.0	2.53	1222.8	707.8	1223.6	515.8	2.371	2.445	3.04	82.10	147.93	2910	2910	12.0
20	FAAU	6.5	2.53	1225.7	710.7	1226.4	515.7	2.377	2.427	2.07	87.98	148.31	2960	2960	14.5
15	FAAU	7.0	2.50	1229.8	713.3	1230.8	517.5	2.376	2.409	1.35	92.34	148.29	2220	2220	18.8
22	FAAU	7.5	2.56	1240.0	716.2	1240.5	524.3	2.365	2.392	1.13	93.92	147.58	2100	2016	22.7
12	JMF	5.0	2.50	1212.8	696.1	1214.0	517.9	2.342	2.483	5.69	66.87	146.13	2920	2920	10.0
6	JMF	5.5	2.53	1219.1	703.3	1220.6	517.3	2.357	2.464	4.36	74.47	147.06	2740	2740	10.3
16	JMF	6.0	2.56	1224.4	709.2	1225.7	516.5	2.371	2.446	3.08	81.89	147.92	2660	2660	11.2
23	JMF	6.5	2.56	1232.5	716.6	1233.4	516.8	2.385	2.428	1.78	89.53	148.82	2670	2670	14.7
13	JMF	7.0	2.56	1226.0	710.6	1227.2	516.6	2.373	2.410	1.53	91.43	148.09	2310	2310	16.5
5	JMF	7.5	2.56	1239.7	716.1	1241.3	525.2	2.360	2.393	1.36	92.73	147.29	2150	2064	20.6

FAA BITUMINOUS CONCRETE TESTING REPORT

REPLICATE 2

SPEC-IMEN NO.	GRAD-ATION	ASPHALT CONTENT PERCENT	THICK-NESS INCHES	WGT----GRAMS IN AIR	IN WATER	SAT.SUR DRY	VOL. CC	SP. GRAVITY ACT.	THEO. GMM	VOID % TOTAL MIX	FILLED VF	UNIT WT TOT.MIX LB/CUFT	STABILITY-LB MEAS-URED	CONV-ERTED	FLOW UNITS OF 1/100 IN
20	FAAL	5.0	2.50	1207.2	698.3	1209.3	511.0	2.362	2.484	4.89	70.29	147.42	2890	2890	10.2
13	FAAL	5.5	2.53	1213.0	701.1	1214.4	513.3	2.363	2.465	4.13	75.51	147.46	2650	2650	10.9
12	FAAL	6.0	2.50	1219.8	708.9	1221.6	512.7	2.379	2.447	2.77	83.47	148.46	2530	2530	12.3
19	FAAL	6.5	2.50	1217.6	709.2	1218.8	509.6	2.389	2.429	1.63	90.31	149.09	2700	2700	15.9
23	FAAL	7.0	2.53	1226.6	711.6	1228.2	516.6	2.374	2.411	1.52	91.47	148.16	2040	2040	17.5
21	FAAL	7.5	2.53	1227.4	709.1	1229.0	519.9	2.361	2.394	1.39	92.61	147.32	1840	1840	21.4
9	FAAM	5.0	2.50	1207.8	699.9	1209.4	509.5	2.371	2.483	4.53	71.96	147.92	2860	2860	9.2
16	FAAM	5.5	2.50	1214.8	707.0	1216.1	509.1	2.386	2.464	3.16	80.29	148.90	3090	3090	12.1
6	FAAM	6.0	2.50	1227.1	716.0	1228.1	512.1	2.396	2.446	2.04	87.38	149.52	2140	2140	15.6
4	FAAM	6.5	2.50	1227.3	717.3	1228.3	511.0	2.402	2.428	1.08	93.40	149.87	2230	2230	18.5
14	FAAM	7.0	2.53	1231.1	714.2	1232.0	517.8	2.378	2.410	1.35	92.38	148.36	2240	2240	17.8
5	FAAM	7.5	2.50	1233.2	712.9	1234.2	521.3	2.366	2.393	1.14	93.83	147.61	1500	1500	23.3
3	FAAU	5.0	2.50	1209.3	695.4	1210.6	515.2	2.347	2.482	5.43	67.94	146.47	2930	2930	10.2
7	FAAU	5.5	2.50	1216.1	705.4	1217.0	511.6	2.377	2.464	3.53	78.41	148.33	2950	2950	10.6
15	FAAU	6.0	2.50	1223.8	712.4	1225.0	512.6	2.387	2.445	2.35	85.64	148.98	2820	2820	14.3
8	FAAU	6.5	2.50	1225.9	712.6	1226.9	514.3	2.384	2.427	1.79	89.47	148.74	2360	2360	16.2
2	FAAU	7.0	2.50	1230.4	713.5	1231.4	517.9	2.376	2.409	1.38	92.19	148.25	2110	2110	18.2
18	FAAU	7.5	2.53	1236.8	714.3	1238.0	521.7	2.362	2.392	1.27	93.19	147.37	1870	1795	21.2
17	JMF	5.0	2.53	1207.3	689.2	1209.1	519.9	2.322	2.483	6.48	63.74	144.90	2670	2670	9.3
11	JMF	5.5	2.56	1215.9	694.4	1217.9	523.5	2.323	2.464	5.74	68.58	144.93	2520	2419	9.5
1	JMF	6.0	2.50	1218.8	699.4	1220.3	520.9	2.340	2.446	4.34	76.02	146.00	2500	2500	10.5
24	JMF	6.5	2.53	1214.6	698.4	1216.1	517.7	2.346	2.428	3.37	81.60	146.40	2340	2340	10.7
22	JMF	7.0	2.56	1227.5	708.1	1228.8	520.7	2.357	2.410	2.18	88.11	147.10	2250	2250	14.1
10	JMF	7.5	2.56	1228.6	708.2	1230.1	521.9	2.354	2.393	1.63	91.41	146.90	2130	2130	16.1

FAA BITUMINOUS CONCRETE TESTING REPORT

REPLICATE 3

SPEC-IMEN NO.	GRAD-ATION	ASPHALT CONTENT PERCENT	THICK-NESS INCHES	WGT----GRAMS IN AIR	IN WATER	SAT.SUR DRY	VOL. CC	SP. GRAVITY ACT.	THEO. GMM	VOID % TOTAL MIX	FILLED VF	UNIT WT TOT.MIX LB/CUFT	STABILITY-LB MEAS-URED	CONV-ERTED	FLOW UNITS OF 1/100 IN
11	FAAL	5.0	2.50	1201.0	680.8	1204.3	523.5	2.294	2.484	7.64	59.54	143.16	2260	2170	9.4
22	FAAL	5.5	2.53	1215.9	704.6	1217.4	512.8	2.371	2.465	3.81	77.04	147.96	2540	2540	11.9
2	FAAL	6.0	2.53	1219.4	705.9	1221.4	515.5	2.365	2.447	3.33	80.68	147.61	2530	2530	11.0
3	FAAL	6.5	2.53	1223.7	712.7	1225.0	512.3	2.389	2.429	1.66	90.16	149.05	2370	2370	13.7
24	FAAL	7.0	2.56	1228.7	712.7	1229.8	517.1	2.376	2.411	1.45	91.85	148.27	2100	2100	14.3
4	FAAL	7.5	2.53	1222.8	707.7	1224.2	516.5	2.367	2.394	1.11	94.02	147.73	1860	1860	18.1
7	FAAM	5.0	2.50	1209.9	696.8	1211.1	514.3	2.353	2.483	5.26	68.70	146.80	2810	2810	10.4
12	FAAM	5.5	2.53	1217.6	703.8	1219.2	515.4	2.362	2.464	4.12	75.55	147.42	2540	2540	10.8
21	FAAM	6.0	2.50	1215.7	704.7	1216.6	511.9	2.375	2.446	2.91	82.77	148.19	2730	2730	13.0
10	FAAM	6.5	2.53	1226.3	712.5	1227.1	514.6	2.383	2.428	1.85	89.13	148.70	2450	2450	14.5
14	FAAM	7.0	2.53	1235.1	715.9	1236.1	520.2	2.374	2.410	1.48	91.66	148.16	2230	2230	16.8
18	FAAM	7.5	2.53	1234.1	713.3	1235.0	521.7	2.366	2.393	1.15	93.81	147.61	1740	1740	20.1
1	FAAU	5.0	2.50	1210.2	698.5	1211.2	512.7	2.360	2.482	4.90	70.26	147.29	3040	3040	10.5
20	FAAU	5.5	2.50	1217.7	708.7	1218.8	510.1	2.387	2.464	3.12	80.50	148.96	3160	3160	11.5
9	FAAU	6.0	2.50	1224.6	714.4	1225.4	511.0	2.396	2.445	1.98	87.66	149.54	2600	2600	15.8
6	FAAU	6.5	2.50	1232.6	718.1	1233.8	515.7	2.390	2.427	1.52	90.93	149.15	2470	2470	18.2
8	FAAU	7.0	2.50	1234.6	718.0	1235.5	517.5	2.386	2.409	0.97	94.42	148.87	1880	1880	20.5
19	FAAU	7.5	2.50	1237.7	716.0	1238.5	522.5	2.369	2.392	0.97	94.73	147.81	1770	1699	25.5
17	JMF	5.0	2.56	1209.8	686.9	1211.4	524.5	2.307	2.483	7.11	61.41	143.93	2480	2381	8.7
13	JMF	5.5	2.56	1212.6	689.9	1214.2	524.3	2.313	2.464	6.14	67.02	144.32	2230	2141	9.5
5	JMF	6.0	2.56	1218.6	696.5	1220.1	523.6	2.327	2.446	4.85	73.84	145.23	2260	2170	10.3
16	JMF	6.5	2.56	1231.3	708.4	1232.8	524.4	2.348	2.428	3.29	81.96	146.52	2500	2400	11.2
23	JMF	7.0	2.53	1231.4	709.6	1232.3	522.7	2.356	2.410	2.25	87.80	147.00	2520	2419	12.6
15	JMF	7.5	2.56	1234.9	710.7	1236.0	525.3	2.351	2.393	1.76	90.75	146.69	2210	2122	15.1

FAA BITUMINOUS CONCRETE TESTING REPORT

REPLICATE 4

SPEC-IMEN NO.	GRAD-ATION	ASPHALT CONTENT PERCENT	THICK-NESS INCHES	WGT----GRAMS IN AIR	IN WATER	SAT.SUR DRY	VOL. CC	SP. GRAVITY ACT.	THEO. GMM	VOID % TOTAL MIX	FILLED VI	UNIT WT TOT.MIX LB/CUFT	STABILITY-LB MEAS-URED	CONV-ERTED	FLOW UNITS OF 1/100 IN
2	FAAL	5.0	2.53	1207.7	693.8	1210.8	517.0	2.336	2.484	5.96	65.77	145.76	2570	2570	10.3
3	FAAL	5.5	2.53	1215.0	700.6	1217.1	516.5	2.352	2.465	4.57	73.52	146.79	2530	2530	9.7
12	FAAL	6.0	2.53	1219.9	710.3	1221.2	510.9	2.388	2.447	2.42	85.30	149.00	2810	2810	12.0
8	FAAL	6.5	2.53	1217.5	708.4	1218.5	510.1	2.387	2.429	1.74	89.75	148.94	2480	2480	14.2
18	FAAL	7.0	2.53	1222.5	709.5	1223.5	514.0	2.378	2.411	1.35	92.35	148.41	2200	2200	15.1
13	FAAL	7.5	2.53	1224.8	707.0	1225.7	518.7	2.361	2.394	1.37	92.70	147.34	1790	1790	16.2
20	FAAM	5.0	2.50	1207.6	695.1	1209.3	514.2	2.349	2.483	5.42	68.00	146.55	2810	2810	9.4
19	FAAM	5.5	2.56	1213.4	705.6	1214.3	508.7	2.385	2.464	3.19	80.11	148.84	2770	2770	10.8
17	FAAM	6.0	2.50	1217.5	709.6	1218.4	508.8	2.393	2.446	2.17	86.63	149.32	2500	2500	13.5
23	FAAM	6.5	2.50	1226.8	713.9	1227.7	513.8	2.388	2.428	1.66	90.16	148.99	2290	2290	14.1
9	FAAM	7.0	2.50	1228.4	713.9	1229.4	515.5	2.383	2.410	1.12	93.57	148.69	2170	2170	18.5
6	FAAM	7.5	2.50	1233.5	713.9	1234.3	520.4	2.370	2.393	0.95	94.84	147.91	1940	1940	24.1
14	FAAH	5.0	2.50	1211.6	699.8	1212.6	512.8	2.363	2.482	4.81	70.67	147.43	3030	3030	10.0
11	FAAH	5.5	2.50	1218.5	705.4	1219.3	513.9	2.371	2.464	3.77	77.22	147.96	3020	3020	11.0
[illegible]	FAAH	6.0	2.50	1220.5	708.7	1221.1	512.4	2.382	2.445	2.58	84.55	148.63	2730	2730	12.8
16	FAAH	6.5	2.56	1228.4	714.3	1228.9	514.6	2.387	2.427	1.64	90.25	148.95	2570	2570	16.3
15	FAAH	7.0	2.53	1231.5	713.9	1232.2	518.3	2.376	2.409	1.37	92.76	148.26	2130	2130	19.0
4	FAAH	7.5	2.53	1236.8	714.7	1237.7	523.0	2.365	2.392	1.14	93.87	147.56	1930	1853	23.0
10	JMF	5.0	2.56	1210.9	688.4	1212.9	524.5	2.309	2.483	7.02	61.71	144.06	2470	2371	8.3
5	JMF	5.5	2.56	1220.8	694.7	1222.7	528.0	2.312	2.464	6.16	65.92	144.28	2410	2314	9.6
22	JMF	6.0	2.56	1219.5	699.7	1220.5	520.8	2.342	2.446	4.27	76.34	146.12	2660	2660	9.2
1	JMF	6.5	2.56	1225.3	704.6	1226.7	522.1	2.347	2.428	3.34	81.74	146.44	2500	2500	10.0
7	JMF	7.0	2.53	1226.8	708.9	1227.5	518.6	2.366	2.410	1.84	89.81	147.61	2550	2550	13.4
21	JMF	7.5	2.53	1226.5	706.2	1227.3	521.1	2.354	2.393	1.64	91.33	146.87	2200	2200	15.0

FAA BITUMINOUS CONCRETE TESTING REPORT

REPLICATE 5

SPEC-IMEN NO.	GRAD-ATION	ASPHALT CONTENT PERCENT	THICK-NESS INCHES	WGT----GRAMS IN AIR	IN WATER	SAT.SUR DRY	VOL. CC	SP. GRAVITY ACT.	THEO. GMM	VOID % TOTAL MIX	FILLED VF	UNIT WT TOT.MIX LB/CUFT	STABILITY-LB MEAS-URED	CONV-ERTED	FLOW UNITS OF 1/100 IN
15	FAAL	5.0	2.53	1209.0	695.9	1210.3	514.4	2.350	2.484	5.38	68.16	146.66	2550	2550	8.9
22	FAAL	5.5	2.53	1215.6	703.3	1216.9	513.6	2.367	2.465	3.98	76.21	147.69	2680	2680	10.1
5	FAAL	6.0	2.50	1218.9	710.3	1219.8	509.5	2.392	2.447	2.23	86.30	149.28	2420	2420	11.7
3	FAAL	6.5	2.53	1227.3	714.4	1228.2	513.8	2.389	2.429	1.66	90.17	149.05	2250	2250	13.6
23	FAAL	7.0	2.50	1227.9	711.9	1228.6	516.7	2.376	2.411	1.43	91.92	148.29	2150	2150	15.6
10	FAAL	7.5	2.56	1231.2	711.9	1232.3	520.4	2.366	2.394	1.17	93.67	147.63	1730	1730	19.0
4	FAAM	5.0	2.53	1212.8	699.5	1213.7	514.2	2.359	2.483	5.01	69.77	147.18	2810	2810	10.0
20	FAAM	5.5	2.50	1219.1	708.9	1219.9	511.0	2.386	2.464	3.18	80.19	148.87	2740	2740	10.6
24	FAAM	6.0	2.50	1221.9	712.8	1222.4	509.6	2.398	2.446	1.97	87.73	149.62	2790	2790	14.1
14	FAAM	6.5	2.50	1228.4	715.6	1229.1	513.5	2.392	2.428	1.47	91.18	149.27	2450	2450	15.9
6	FAAM	7.0	2.50	1233.7	716.8	1234.6	517.8	2.383	2.410	1.14	93.49	148.67	2200	2200	19.7
13	FAAM	7.5	2.56	1241.3	717.1	1242.0	524.9	2.365	2.393	1.18	93.66	147.57	1980	1862	20.0
8	FAAU	5.0	2.53	1211.3	695.9	1212.6	516.7	2.344	2.482	5.55	67.44	146.28	3040	3040	9.7
19	FAAU	5.5	2.53	1218.2	704.4	1218.8	514.4	2.368	2.464	3.89	76.66	147.78	2950	2950	10.1
21	FAAU	6.0	2.50	1223.5	710.5	1223.9	513.4	2.383	2.445	2.53	84.71	148.71	2850	2850	13.8
18	FAAU	6.5	2.50	1231.1	715.2	1231.5	516.3	2.384	2.427	1.75	89.66	148.79	2460	2460	15.9
11	FAAU	7.0	2.50	1236.3	716.8	1236.8	520.0	2.377	2.409	1.31	92.58	148.36	2280	2280	17.8
17	FAAU	7.5	2.56	1243.2	717.0	1243.6	526.6	2.361	2.392	1.30	93.01	147.31	1850	1776	20.0
12	JMF	5.0	2.56	1210.3	688.5	1212.0	523.5	2.312	2.483	6.89	62.19	144.26	2470	2371	9.6
1	JMF	5.5	2.56	1216.0	693.9	1217.3	523.4	2.323	2.464	5.71	68.69	144.97	2390	2294	9.7
16	JMF	6.0	2.53	1221.9	702.4	1223.0	520.6	2.347	2.446	4.04	77.35	146.46	2590	2590	9.8
7	JMF	6.5	2.53	1227.3	707.4	1228.0	520.6	2.357	2.428	2.90	83.80	147.11	2510	2510	11.5
9	JMF	7.0	2.56	1234.0	712.7	1234.6	521.9	2.364	2.410	1.87	89.56	147.54	2360	2360	12.3
2	JMF	7.5	2.56	1236.2	712.5	1236.8	524.3	2.358	2.393	1.47	92.18	147.13	2240	2150	16.5

FAA BITUMINOUS CONCRETE TESTING REPORT

REPLICATE 6

SPEC-IMEN NO.	GRAD-ATION	ASPHALT CONTENT PERCENT	THICK-NESS INCHES	WGT----GRAMS IN AIR	IN WATER	SAT.SUR DRY	VOL. CC	SP. GRAVITY ACT.	THEO. GMM	VOID % TOTAL MIX	FILLED VF	UNIT WT TOT.MIX LB/CUFT	STABILITY-LB MEAS-URED	CONV-ERTED	FLOW UNITS OF 1/100 IN
5	FAAI	5.0	2.53	1212.5	698.0	1213.9	515.9	2.350	2.484	5.38	68.15	146.66	2560	2560	9.9
18	FAAI	5.5	2.50	1213.0	701.2	1214.4	513.2	2.364	2.465	4.11	75.60	147.49	2600	2600	9.8
26	FAAI	6.0	2.53	1221.5	707.7	1222.6	514.9	2.372	2.447	3.05	82.05	148.03	2340	2340	10.7
15	FAAI	6.5	2.50	1225.9	711.8	1226.7	514.9	2.381	2.429	1.98	88.44	148.57	2690	2690	13.1
3	FAAI	7.0	2.50	1226.9	711.8	1227.9	516.1	2.377	2.411	1.40	92.10	148.34	2430	2430	16.2
1	FAAI	7.5	2.53	1234.8	714.3	1235.9	521.6	2.367	2.394	1.11	93.99	147.72	2090	2090	17.0
16	FAAM	5.0	2.50	1208.8	696.7	1209.6	512.9	2.357	2.483	5.08	69.45	147.06	2720	2720	9.5
22	FAAM	5.5	2.50	1217.7	707.0	1218.3	511.3	2.382	2.464	3.35	79.33	148.61	2940	2940	10.8
29	FAAM	6.0	2.50	1220.8	710.7	1221.5	510.8	2.390	2.446	2.29	85.99	149.13	2770	2770	12.7
35	FAAM	6.5	2.50	1227.1	718.6	1227.9	513.3	2.391	2.428	1.54	90.82	149.17	2360	2360	15.1
41	FAAM	7.0	2.50	1232.0	715.8	1232.8	518.0	2.378	2.410	1.31	92.56	148.41	2220	2220	19.5
7	FAAM	7.5	2.53	1237.2	715.5	1238.1	522.6	2.367	2.393	1.07	94.31	147.73	1890	1728	21.4
21	FAAU	5.0	2.50	1210.0	698.1	1210.7	512.6	2.361	2.482	4.89	70.27	147.30	3360	3360	9.5
19	FAAU	5.5	2.50	1214.0	702.4	1214.7	512.3	2.370	2.464	3.83	76.95	147.87	3080	3080	11.1
12	FAAU	6.0	2.50	1220.8	710.1	1221.3	511.2	2.388	2.445	2.33	85.79	149.02	2960	2960	13.3
14	FAAU	6.5	2.50	1225.8	712.6	1226.4	513.8	2.386	2.427	1.70	89.95	148.87	2550	2550	15.4
[illegible]	FAAU	7.0	2.50	1234.3	716.5	1234.8	518.3	2.381	2.409	1.16	93.46	148.60	2220	2220	19.3
[illegible]	FAAU	7.5	2.53	1240.3	716.6	1241.1	524.5	2.365	2.392	1.14	93.85	147.56	1970	1891	20.3
13	JBI	5.0	2.56	1208.8	685.9	1210.4	524.5	2.305	2.483	7.18	61.14	143.81	2470	2371	8.7
2	JBI	5.5	2.56	1215.9	695.1	1217.1	522.0	2.329	2.464	5.47	69.68	145.35	2780	2780	9.5
17	JBI	6.0	2.53	1218.6	699.5	1219.4	519.9	2.344	2.446	4.17	76.76	146.26	2670	2670	9.0
8	JBI	6.5	2.50	1228.7	706.5	1229.5	523.1	2.349	2.428	3.26	82.12	146.57	2570	2467	10.9
23	JBI	7.0	2.56	1232.2	710.6	1232.9	522.1	2.360	2.410	2.07	88.66	147.27	2400	2400	13.2
7	JBI	7.5	2.56	1236.4	713.0	1237.1	524.1	2.359	2.393	1.42	92.45	147.21	2210	2122	17.2

AD-A153 469 FIELD VALIDATION OF STATISTICALLY-BASED ACCEPTANCE PLAN FOR BITUMINOUS AI..(U) CLEMSON UNIV S C DEPT OF CIVIL ENGINEERING J L BURATI ET AL. MAY 84 2/2

UNCLASSIFIED DOT/FAA/PM-84/12-VOL-1 DTFA01-81-C-10057 F/G 1/5 NL

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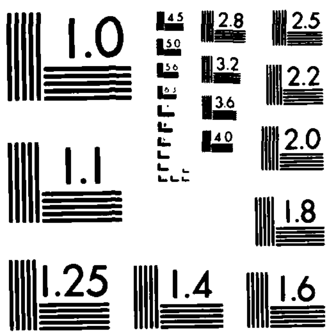


FAA BITUMINOUS CONCRETE TESTING REPORT

REPLICATE 7

SPEC-IMEN NO.	GRAD-ATION	ASPHALT CONTENT PERCENT	THICK-NESS INCHES	WGT----GRAMS IN AIR	IN WATER	SAT.SUR DRY	VOL. CC	SP. GRAVITY ACT.	THEO. GMM	VOID % TOTAL MIX	FILLED VF	UNIT WT TOT.MIX LB/CUFT	STABILITY-LB MEAS-URED	CONV-ERTED	FLOW UNITS OF 1/100 IN
17	FAAL	5.0	2.56	1212.4	696.9	1215.2	518.3	2.339	2.484	5.83	66.29	145.97	2280	2280	8.6
15	FAAL	5.5	2.50	1217.6	703.3	1219.0	515.7	2.361	2.465	4.22	75.12	147.33	2510	2510	10.3
13	FAAL	6.0	2.50	1221.7	709.0	1223.0	514.0	2.377	2.447	2.87	82.98	148.32	2710	2710	12.5
5	FAAL	6.5	2.53	1228.0	713.3	1229.2	515.9	2.380	2.429	2.00	88.33	148.53	2290	2290	12.1
4	FAAL	7.0	2.53	1231.3	714.2	1232.0	517.8	2.378	2.411	1.37	92.25	148.38	2250	2250	15.8
8	FAAL	7.5	2.53	1234.6	713.9	1235.6	521.7	2.366	2.394	1.15	93.81	147.67	2060	2060	20.1
21	FAAM	5.0	2.50	1211.1	699.4	1212.0	512.6	2.363	2.483	4.85	70.50	147.43	2790	2790	9.0
16	FAAM	5.5	2.50	1218.5	706.6	1219.6	513.0	2.375	2.464	3.60	78.05	148.22	2840	2840	10.7
9	FAAM	6.0	2.50	1224.3	711.0	1225.1	514.1	2.381	2.446	2.64	84.15	148.60	2650	2650	12.1
12	FAAM	6.5	2.50	1230.5	715.5	1231.0	515.5	2.387	2.428	1.69	90.01	148.95	2480	2480	16.0
24	FAAM	7.0	2.50	1234.1	715.9	1234.6	518.7	2.379	2.410	1.28	92.74	148.46	2190	2190	19.8
1	FAAM	7.5	2.53	1238.1	715.4	1238.9	523.5	2.365	2.393	1.17	93.70	147.58	1920	1843	22.9
7	FAAU	5.0	2.53	1211.4	696.3	1212.8	516.5	2.345	2.482	5.50	67.63	146.35	3280	3280	9.7
20	FAAU	5.5	2.50	1216.8	705.7	1217.3	511.6	2.378	2.464	3.47	78.69	148.41	3130	3130	9.5
18	FAAU	6.0	2.50	1223.4	709.8	1224.0	514.2	2.379	2.445	2.69	83.88	148.46	2680	2680	12.0
22	FAAU	6.5	2.50	1228.5	712.7	1229.1	516.4	2.379	2.427	1.98	88.45	148.45	2650	2650	14.6
19	FAAU	7.0	2.50	1235.0	716.5	1235.6	519.1	2.379	2.409	1.24	92.94	148.46	2250	2250	18.7
23	FAAU	7.5	2.53	1239.2	714.7	1239.8	525.1	2.360	2.392	1.34	92.83	147.26	1910	1834	21.5
10	JMF	5.0	2.56	1212.8	690.1	1214.7	524.6	2.312	2.483	6.89	62.18	144.26	2340	2246	9.2
3	JMF	5.5	2.56	1216.8	694.9	1218.2	523.3	2.325	2.464	5.63	69.01	145.10	2490	2390	9.1
2	JMF	6.0	2.56	1222.2	701.2	1223.0	521.8	2.342	2.446	4.24	76.47	146.16	2490	2490	9.6
14	JMF	6.5	2.56	1229.7	708.0	1230.5	522.5	2.353	2.428	3.07	83.01	146.86	2510	2410	11.2
6	JMF	7.0	2.56	1234.8	712.5	1235.7	523.2	2.360	2.410	2.07	88.66	147.27	2410	2314	13.8
11	JMF	7.5	2.53	1239.2	714.2	1239.8	525.6	2.358	2.393	1.48	92.16	147.12	2260	2170	17.9

FAA BITUMINOUS CONCRETE TESTING REPORT

REPLICATE 8

SPEC-IMEN NO.	GRAD-ATION	ASPHALT CONTENT PERCENT	THICK-NESS INCHES	WGT----GRAMS IN AIR	IN WATER	SAT.SUR DRY	VOL. CC	SP. GRAVITY ACT.	THEO. GMM	VOID % TOTAL MIX	FILLED VF	UNIT WT TOT.MIX LB/CUFT	STABILITY-LB MEAS-URED	CONV-ERTED	FLOW UNITS OF 1/100 IN
12	FAAI	5.0	2.53	1210.2	696.8	1211.4	514.6	2.352	2.484	5.32	68.40	146.75	2380	2380	8.9
20	FAAI	5.5	2.53	1217.5	702.9	1218.8	515.9	2.360	2.465	4.26	74.91	147.26	2300	2300	9.2
6	FAAI	6.0	2.50	1219.0	707.7	1219.8	512.1	2.380	2.447	2.72	83.72	148.54	2510	2510	11.7
1	FAAI	6.5	2.53	1226.5	711.9	1227.6	515.7	2.378	2.429	2.09	87.90	148.41	2360	2360	12.7
3	FAAI	7.0	2.53	1230.4	713.7	1230.9	517.2	2.379	2.411	1.33	92.47	148.45	2320	2320	15.7
4	FAAI	7.5	2.53	1233.6	713.3	1234.4	521.1	2.367	2.394	1.12	93.98	147.72	1950	1950	18.3
11	FAAM	5.0	2.53	1212.0	697.6	1213.4	515.8	2.350	2.483	5.37	68.22	146.62	2760	2760	8.8
2	FAAM	5.5	2.53	1217.6	705.9	1218.4	512.5	2.376	2.464	3.58	78.16	148.25	3020	3020	10.7
14	FAAM	6.0	2.50	1223.8	712.4	1224.3	511.9	2.391	2.446	2.26	86.15	149.18	2860	2860	12.0
13	FAAM	6.5	2.50	1228.8	715.0	1229.4	514.4	2.389	2.428	1.61	90.41	149.06	2440	2440	14.8
21	FAAM	7.0	2.53	1235.0	715.8	1235.5	519.7	2.376	2.410	1.40	92.12	148.29	1990	1990	17.4
24	FAAM	7.5	2.56	1238.6	714.7	1239.3	524.6	2.361	2.393	1.34	92.86	147.33	1710	1642	22.7
17	FAAU	5.0	2.53	1209.5	696.2	1210.1	513.9	2.354	2.482	5.17	69.04	146.86	3060	3060	9.6
9	FAAU	5.5	2.50	1214.3	701.7	1214.9	513.2	2.366	2.464	3.97	76.26	147.65	3050	3050	9.4
10	FAAU	6.0	2.50	1223.6	710.0	1224.0	514.0	2.381	2.445	2.64	84.16	148.55	2980	2980	12.0
8	FAAU	6.5	2.50	1230.9	714.8	1231.4	516.6	2.383	2.427	1.83	89.27	148.68	2520	2520	15.0
18	FAAU	7.0	2.53	1237.5	716.4	1237.9	521.5	2.373	2.409	1.50	91.59	148.07	2240	2240	19.0
23	FAAU	7.5	2.56	1242.1	716.5	1242.5	526.0	2.361	2.392	1.28	93.14	147.35	1930	1853	21.6
22	JMI	5.0	2.56	1210.4	686.1	1211.9	525.8	2.302	2.483	7.29	60.76	143.65	2290	2198	8.6
7	JMI	5.5	2.56	1214.4	692.9	1215.6	522.7	2.323	2.464	5.71	68.69	144.98	2540	2438	9.5
15	JMI	6.0	2.56	1223.9	701.8	1224.5	522.7	2.341	2.446	4.27	76.32	146.11	2500	2400	9.4
5	JMI	6.5	2.56	1228.1	706.6	1228.8	522.2	2.352	2.428	3.14	82.68	146.75	2620	2620	10.3
16	JMI	7.0	2.56	1234.6	711.0	1235.4	524.4	2.354	2.410	2.31	87.49	146.91	2430	2333	13.9
19	JMI	7.5	2.56	1237.8	712.4	1238.5	526.1	2.353	2.393	1.68	91.15	146.81	2140	2054	15.5

FAA BITUMINOUS CONCRETE TESTING REPORT

REPLICATE 9

SPEC-IMEN NO.	GRAD-ATION	ASPHALT CONTENT PERCENT	THICK-NESS INCHES	WGT----GRAMS IN AIR	IN WATER	SAT.SUR DRY	VOL. CC	SP. GRAVITY ACT.	THEO. CMM	VOID % TOTAL MIX	FILLED VF	UNIT WT TOT.MIX LB/CUFT	STABILITY-LB MEAS-URED	CONV-ERTED	FLOW UNITS OF 1/100 IN
12	FAAL	5.0	2.56	1211.0	695.1	1214.1	519.0	2.333	2.484	6.07	65.35	145.60	2130	2130	9.5
14	FAAL	5.5	2.53	1215.2	701.4	1216.2	514.8	2.361	2.465	4.24	75.02	147.30	2450	2450	9.8
18	FAAL	6.0	2.53	1221.8	709.5	1222.8	513.3	2.380	2.447	2.73	83.70	148.53	2490	2490	11.1
10	FAAL	6.5	2.53	1223.7	710.3	1224.4	514.1	2.380	2.429	2.01	88.32	148.53	2190	2190	12.9
6	FAAL	7.0	2.53	1231.0	714.3	1231.7	517.4	2.379	2.411	1.32	92.53	148.46	2080	2080	15.1
7	FAAL	7.5	2.56	1234.0	713.4	1234.6	521.2	2.368	2.394	1.10	94.05	147.74	2120	2120	18.5
23	FAAM	5.0	2.50	1210.4	700.4	1211.3	510.9	2.369	2.483	4.59	71.69	147.84	3000	3000	10.3
17	FAAM	5.5	2.50	1218.5	706.5	1219.3	512.8	2.376	2.464	3.56	78.23	148.27	2800	2800	11.3
1	FAAM	6.0	2.50	1222.8	712.5	1223.5	511.0	2.393	2.446	2.17	86.65	149.32	2710	2710	12.6
8	FAAM	6.5	2.50	1227.1	714.9	1227.6	512.7	2.393	2.428	1.42	91.46	149.35	2470	2470	16.1
13	FAAM	7.0	2.53	1233.6	715.2	1234.3	519.1	2.376	2.410	1.39	92.13	148.29	2070	2070	18.2
2	FAAM	7.5	2.53	1237.2	715.3	1238.0	522.7	2.367	2.393	1.09	94.11	147.70	1960	1882	22.0
3	FAAU	5.0	2.53	1210.3	694.5	1211.0	516.5	2.343	2.482	5.59	67.27	146.22	2980	2980	9.6
19	FAAU	5.5	2.50	1216.9	704.8	1217.3	512.5	2.374	2.464	3.63	77.89	148.16	2770	2770	12.3
16	FAAU	6.0	2.56	1224.3	710.9	1224.8	513.9	2.382	2.445	2.56	84.55	148.66	3010	3010	13.0
4	FAAU	6.5	2.53	1231.7	714.9	1232.1	517.2	2.381	2.427	1.88	89.00	148.60	2480	2480	15.0
22	FAAU	7.0	2.53	1236.8	716.3	1237.1	520.8	2.375	2.409	1.42	91.99	148.19	2180	2180	17.6
24	FAAU	7.5	2.53	1239.6	714.6	1240.0	525.4	2.359	2.392	1.37	92.70	147.22	1920	1843	21.0
15	JMF	5.0	2.56	1210.4	688.6	1211.3	522.7	2.316	2.483	6.74	62.75	144.50	2540	2438	8.5
20	JMF	5.5	2.56	1216.4	696.6	1217.0	520.4	2.337	2.464	5.14	71.05	145.86	2430	2430	8.0
11	JMF	6.0	2.56	1222.2	700.4	1223.1	522.7	2.338	2.446	4.41	75.74	145.91	2310	2218	8.8
5	JMF	6.5	2.56	1227.9	705.4	1228.5	523.1	2.347	2.428	3.32	81.83	146.47	2470	2371	10.7
21	JMF	7.0	2.53	1234.2	711.4	1234.7	523.3	2.358	2.410	2.14	88.34	147.17	2270	2179	13.7
9	JMF	7.5	2.56	1239.8	713.3	1240.2	526.9	2.353	2.393	1.67	91.19	146.83	2140	2054	16.6

FAA BITUMINOUS CONCRETE TESTING REPORT

REPLICATE 10

SPEC-IMEN NO.	GRAD-ATION	ASPHALT CONTENT PERCENT	THICK-NESS INCHES	WGT----GRAMS IN AIR	IN WATER	SAT.SUR DRY	VOL. CC	SP. GRAVITY ACT.	THEO. GMM	VOID % TOTAL MIX	FILLED VF	UNIT WT TOT.MIX LB/CUFT	STABILITY-LB MEAS-URED	CONV-ERTED	FLOW UNITS OF 1/100 IN
18	FAAI	5.0	2.56	1211.7	696.9	1213.3	516.4	2.346	2.484	5.54	67.50	146.42	2270	2270	9.2
14	FAAI	5.5	2.53	1217.1	704.2	1218.4	514.2	2.367	2.465	3.98	76.24	147.70	2550	2550	9.8
7	FAAI	6.0	2.53	1220.2	707.2	1221.1	513.9	2.374	2.447	2.97	82.48	148.16	2330	2330	10.4
11	FAAI	6.5	2.53	1229.3	713.0	1230.4	517.4	2.376	2.429	2.19	87.39	148.26	2530	2530	13.5
1	FAAI	7.0	2.50	1229.6	713.8	1230.3	516.5	2.381	2.411	1.26	92.84	148.55	2420	2420	17.5
9	FAAI	7.5	2.53	1234.9	712.9	1235.7	522.8	2.362	2.394	1.33	92.87	147.39	1940	1862	18.3
21	FAAM	5.0	2.50	1211.8	700.6	1212.5	511.9	2.367	2.483	4.66	71.34	147.72	2760	2760	8.7
22	FAAM	5.5	2.50	1217.5	707.2	1217.9	510.7	2.384	2.464	3.25	79.83	148.76	2910	2910	11.5
20	FAAM	6.0	2.53	1225.0	712.4	1225.7	513.3	2.387	2.446	2.43	85.24	148.92	2600	2600	12.5
5	FAAM	6.5	2.53	1231.1	716.6	1231.7	515.1	2.390	2.428	1.56	90.69	149.14	2700	2700	17.0
8	FAAM	7.0	2.53	1232.1	715.2	1232.5	517.3	2.382	2.410	1.17	93.32	148.62	2170	2170	18.7
24	FAAM	7.5	2.56	1238.4	715.4	1239.0	523.6	2.365	2.393	1.16	93.73	147.59	1790	1718	20.1
19	FAAU	5.0	2.53	1212.7	697.6	1213.5	515.9	2.351	2.482	5.29	68.53	146.68	2960	2960	10.0
12	FAAU	5.5	2.53	1218.4	704.6	1218.8	514.2	2.370	2.464	3.83	76.91	147.86	2840	2840	9.2
10	FAAU	6.0	2.50	1226.5	712.4	1227.0	514.6	2.383	2.445	2.52	84.77	148.72	2900	2900	12.7
13	FAAU	6.5	2.50	1230.2	715.4	1230.7	515.3	2.387	2.427	1.63	90.30	148.97	2670	2670	15.5
6	FAAU	7.0	2.53	1237.7	717.3	1238.1	520.8	2.377	2.409	1.35	92.37	148.30	2280	2280	18.2
4	FAAU	7.5	2.56	1243.7	717.6	1244.1	526.5	2.362	2.392	1.25	93.31	147.40	1900	1824	22.5
17	JMF	5.0	2.53	1212.6	688.9	1213.8	524.9	2.310	2.483	6.96	61.93	144.15	2350	2256	9.2
23	JMF	5.5	2.53	1218.0	695.3	1219.1	523.8	2.325	2.464	5.63	69.02	145.10	2500	2400	8.5
16	JMF	6.0	2.53	1222.1	699.9	1222.9	523.0	2.337	2.446	4.47	75.47	145.81	2480	2381	9.5
2	JMF	6.5	2.56	1227.3	706.9	1227.9	521.0	2.356	2.428	2.98	83.44	146.99	2730	2730	10.7
3	JMF	7.0	2.56	1234.6	712.6	1235.2	522.6	2.362	2.410	1.97	89.14	147.41	2480	2381	12.8
15	JMF	7.5	2.56	1240.1	714.4	1240.8	526.4	2.356	2.393	1.55	91.77	147.00	2190	2102	16.4

FAA BITUMINOUS CONCRETE TESTING REPORT

REPLICATE 11

SPEC-IMEN NO.	GRAD-ATION	ASPHALT CONTENT PERCENT	THICK-NESS INCHES	WGT----GRAMS IN AIR	IN WATER	SAT.SUR DRY	VOL. CC	SP. GRAVITY ACT.	THEO. GMM	VOID % TOTAL MIX	FILLED VF	UNIT WT TOT.MIX LB/CUFT	STABILITY-LB MEAS-URED	CONV-ERTED	FLOW UNITS OF 1/100 IN
13	FAAL	5.0	2.53	1211.3	694.8	1213.6	518.8	2.335	2.484	6.01	65.58	145.69	2410	2410	9.5
19	FAAL	5.5	2.50	1215.4	704.9	1216.4	511.5	2.376	2.465	3.60	78.04	148.27	2670	2670	9.6
20	FAAL	6.0	2.50	1221.7	709.1	1222.7	513.6	2.379	2.447	2.79	83.37	148.43	2290	2290	10.6
2	FAAL	6.5	2.50	1226.9	712.6	1227.8	515.2	2.381	2.429	1.96	88.56	148.60	2700	2700	15.3
22	FAAL	7.0	2.53	1227.6	712.5	1228.2	515.7	2.380	2.411	1.27	92.80	148.54	2050	2050	15.2
1	FAAL	7.5	2.56	1234.5	713.4	1235.1	521.7	2.366	2.394	1.16	93.77	147.66	1880	1880	19.1
3	FAAM	5.0	2.50	1213.6	699.2	1214.9	515.7	2.353	2.483	5.22	68.83	146.85	2720	2720	9.5
14	FAAM	5.5	2.50	1217.1	706.6	1217.9	511.3	2.380	2.464	3.39	79.09	148.54	2930	2930	11.8
4	FAAM	6.0	2.50	1223.9	712.2	1224.6	512.4	2.389	2.446	2.35	85.68	149.05	2590	2590	12.2
5	FAAM	6.5	2.50	1230.7	715.7	1231.2	515.5	2.387	2.428	1.67	90.10	148.97	2340	2340	16.3
17	FAAM	7.0	2.53	1234.1	715.9	1234.7	518.8	2.379	2.410	1.30	92.64	148.43	2000	2000	19.3
15	FAAM	7.5	2.53	1238.5	715.5	1239.2	523.7	2.365	2.393	1.17	93.68	147.57	2000	1920	22.5
11	FAAU	5.0	2.50	1212.4	698.5	1213.1	514.6	2.356	2.482	5.08	69.47	147.01	2920	2920	9.5
9	FAAU	5.5	2.53	1217.9	702.5	1218.6	516.1	2.360	2.464	4.23	75.06	147.25	2830	2830	9.7
23	FAAU	6.0	2.50	1224.4	710.3	1224.8	514.5	2.380	2.445	2.67	84.00	148.50	2800	2800	11.8
21	FAAU	6.5	2.53	1231.4	715.0	1231.8	516.8	2.383	2.427	1.82	89.28	148.68	2450	2450	14.5
7	FAAU	7.0	2.53	1234.7	715.2	1235.2	520.0	2.374	2.409	1.44	91.90	148.16	2150	2150	18.7
12	FAAU	7.5	2.53	1240.5	716.4	1241.1	524.7	2.364	2.392	1.16	93.74	147.53	2000	1920	20.3
10	JMF	5.0	2.56	1211.5	688.3	1213.1	524.8	2.308	2.483	7.03	61.69	144.05	2440	2342	8.5
6	JMF	5.5	2.56	1216.7	693.6	1217.5	523.9	2.322	2.464	5.75	68.54	144.92	2450	2352	8.7
8	JMF	6.0	2.56	1223.8	699.8	1224.6	524.8	2.332	2.446	4.66	74.63	145.51	2430	2333	9.3
16	JMF	6.5	2.53	1230.2	708.8	1230.8	522.0	2.357	2.428	2.94	83.65	147.06	2620	2620	10.6
18	JMF	7.0	2.56	1235.9	713.9	1236.4	522.5	2.365	2.410	1.85	89.76	147.60	2370	2275	14.0
24	JMF	7.5	2.53	1234.3	710.9	1234.9	524.0	2.356	2.393	1.57	91.71	146.99	2260	2170	17.2

FAA BITUMINOUS CONCRETE TESTING REPORT

REPLICATE 12

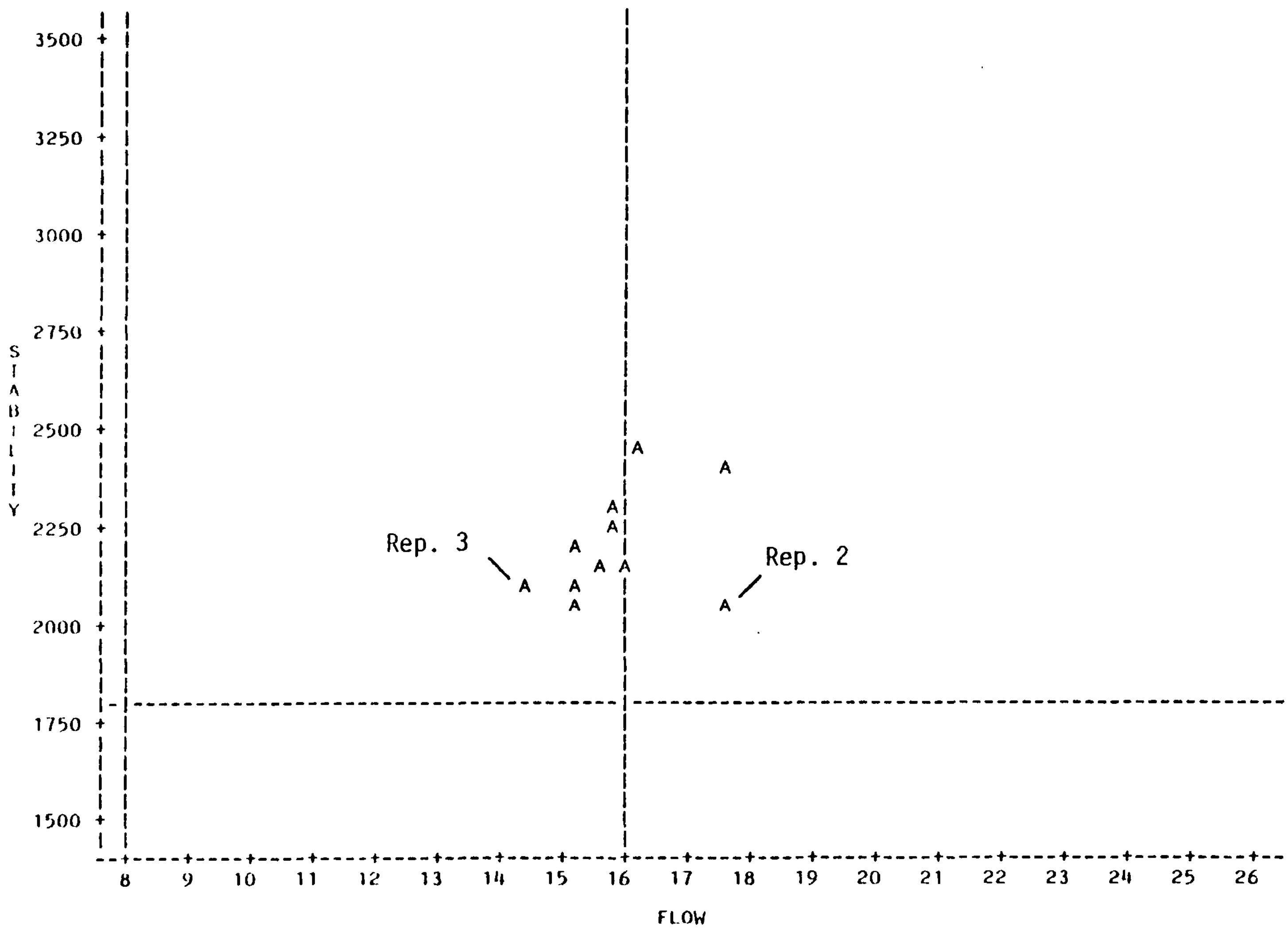
SPEC-IMEN NO.	GRAD-ATION	ASPHALT CONTENT PERCENT	THICK-NESS INCHES	WGT---GRAMS IN AIR	IN WATER	SAT.SUR DRY	VOL. CC	SP. GRAVITY ACT.	THEO. GMM	VOID % TOTAL MIX	FILLED VF	UNIT WT TOT.MIX LB/CUFT	STABILITY-LB MEAS-URED	CONV-ERTED	FLOW UNITS OF 1/100 IN
17	FAAI	5.0	2.53	1211.3	697.2	1213.1	515.9	2.348	2.484	5.48	67.75	146.51	2240	2240	9.0
18	FAAI	5.5	2.50	1216.1	703.6	1217.3	513.7	2.367	2.465	3.96	76.31	147.72	2270	2270	9.6
22	FAAI	6.0	2.53	1224.5	712.3	1225.1	512.8	2.388	2.447	2.42	85.32	149.00	2600	2600	11.6
23	FAAI	6.5	2.53	1226.9	713.7	1227.6	513.9	2.387	2.429	1.71	89.89	148.98	2100	2100	12.5
8	FAAI	7.0	2.53	1228.8	713.2	1229.4	516.2	2.380	2.411	1.27	92.81	148.54	2170	2170	16.0
16	FAAI	7.5	2.53	1235.4	713.7	1236.1	522.4	2.365	2.394	1.22	93.46	147.57	1770	1770	19.7
1	FAAM	5.0	2.53	1211.9	699.6	1212.8	513.2	2.361	2.483	4.89	70.28	147.35	2820	2820	9.5
10	FAAM	5.5	2.50	1217.7	707.4	1218.3	510.9	2.383	2.464	3.27	79.72	148.73	2600	2600	10.5
5	FAAM	6.0	2.50	1224.2	713.1	1225.0	511.9	2.391	2.446	2.23	86.32	149.23	2480	2480	12.0
12	FAAM	6.5	2.50	1229.3	716.0	1229.7	513.7	2.393	2.428	1.44	91.37	149.33	2260	2260	15.5
4	FAAM	7.0	2.53	1234.3	716.8	1234.9	518.1	2.382	2.410	1.15	93.44	148.66	2020	2020	17.5
13	FAAM	7.5	2.53	1238.4	715.7	1238.9	523.2	2.367	2.393	1.09	94.12	147.70	1800	1728	21.6
19	FAAU	5.0	2.53	1211.4	693.8	1212.2	518.4	2.337	2.482	5.85	66.19	145.82	2800	2800	8.9
2	FAAU	5.5	2.50	1217.5	705.5	1218.1	512.6	2.375	2.464	3.61	78.03	148.21	3080	3080	10.4
3	FAAU	6.0	2.53	1222.9	709.7	1223.5	513.8	2.380	2.445	2.65	84.06	148.52	2870	2870	12.0
20	FAAU	6.5	2.50	1228.6	714.0	1229.0	515.0	2.386	2.427	1.70	89.92	148.86	2510	2510	16.3
24	FAAU	7.0	2.53	1235.3	715.4	1235.7	520.3	2.374	2.409	1.44	91.86	148.15	2100	2100	20.0
14	FAAU	7.5	2.56	1239.6	715.9	1240.1	524.2	2.365	2.392	1.14	93.85	147.56	2130	2045	24.2
9	JMF	5.0	2.56	1211.1	688.8	1212.2	523.4	2.314	2.483	6.81	62.49	144.39	2240	2150	8.4
6	JMF	5.5	2.56	1216.8	697.2	1217.4	520.2	2.339	2.464	5.07	71.33	145.96	2660	2660	9.0
15	JMF	6.0	2.53	1224.1	704.1	1224.9	520.8	2.350	2.446	3.91	77.97	146.67	2540	2540	9.8
21	JMF	6.5	2.53	1230.6	711.1	1231.2	520.1	2.366	2.428	2.55	85.53	147.64	2680	2680	11.7
7	JMF	7.0	2.56	1234.3	713.1	1234.8	521.7	2.366	2.410	1.83	89.88	147.63	2500	2500	13.6
11	JMF	7.5	2.56	1238.7	713.0	1239.2	526.2	2.354	2.393	1.63	91.40	146.89	2120	2035	16.5

Appendix C

Marshall Property Scatter Plots with Outliers from Replicates Two and Three Identified

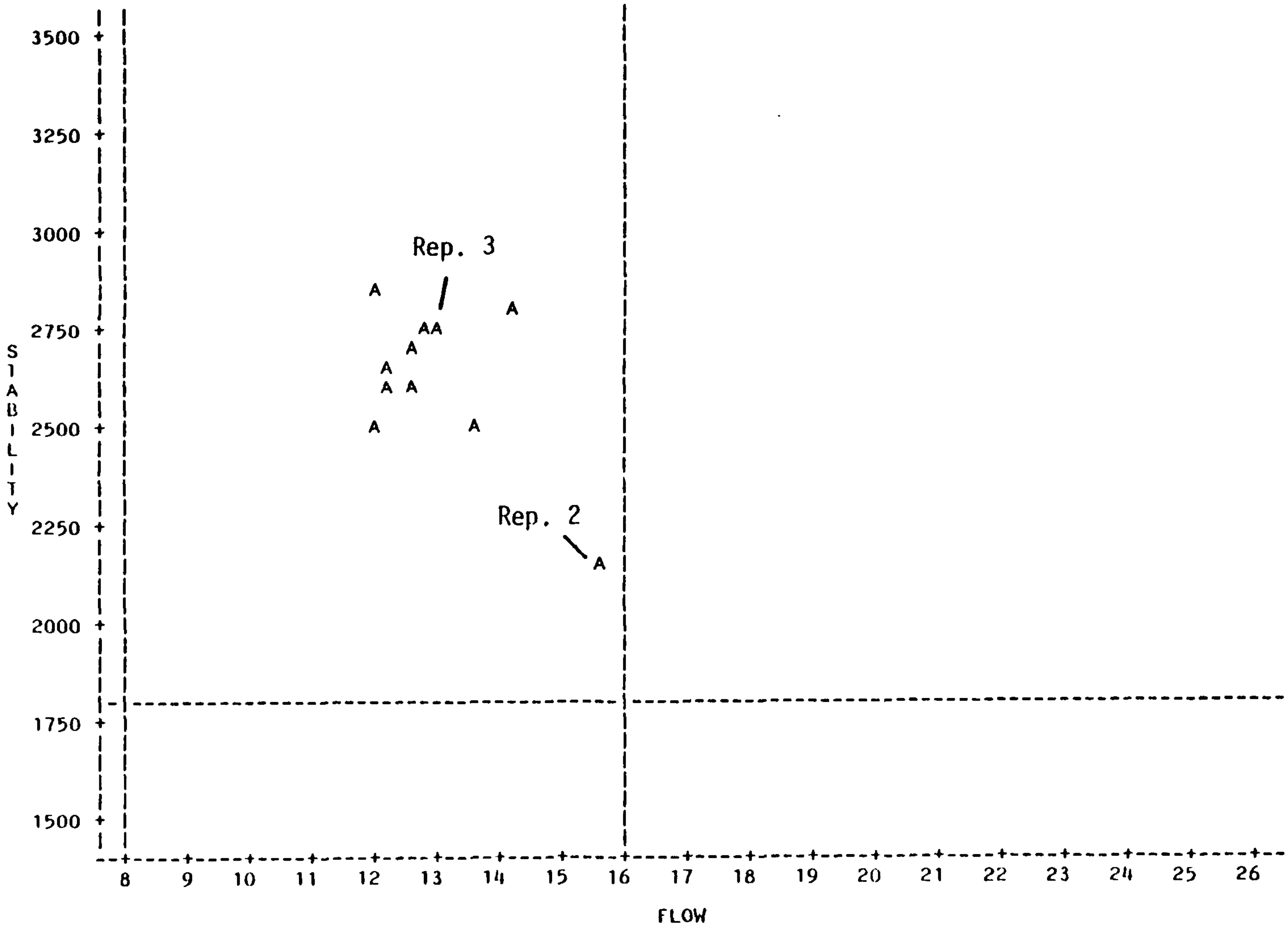
STABILITY VS. FLOW
GRADATIO=FAAL ASPHALT CONTENT=7

LEGEND: A = 1 OBS, B = 2 OBS, ETC.

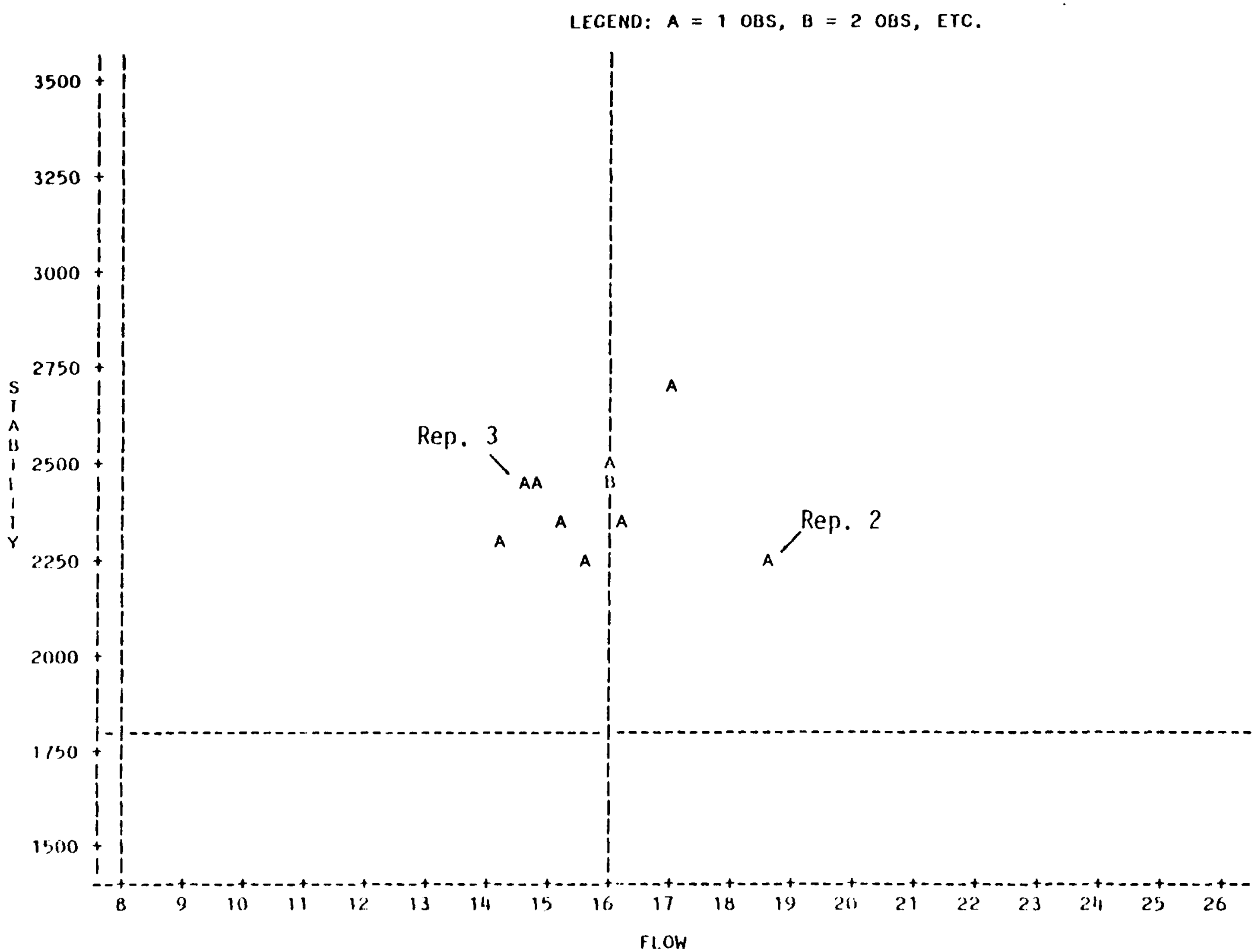


STABILITY VS. FLOW
GRADATIO=FAAM   ASPHALT CONTENT=6

LEGEND: A = 1 OBS, B = 2 OBS, ETC.

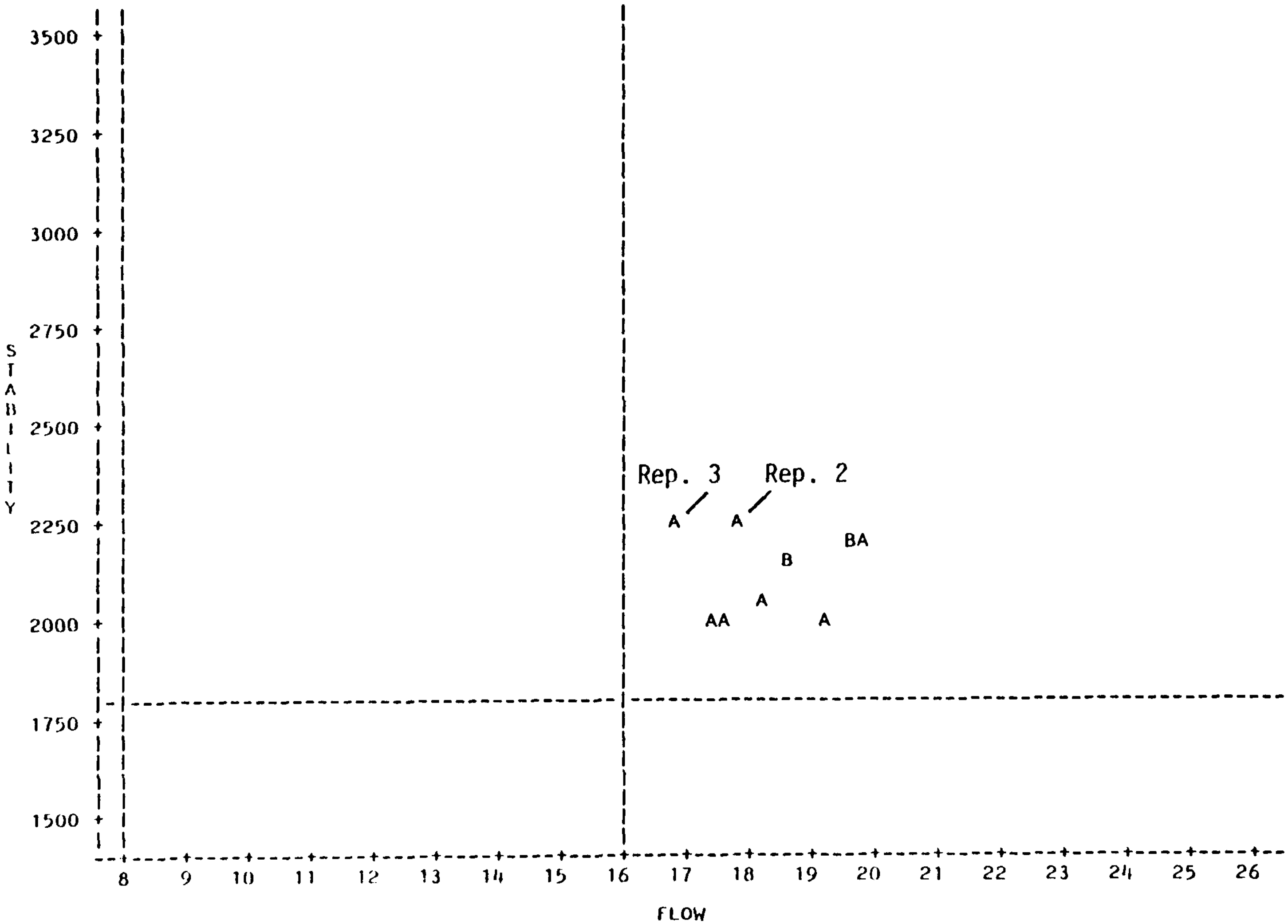


STABILITY VS. FLOW
GRADATIO=FAAM   ASPHALT CONTENT=6.5



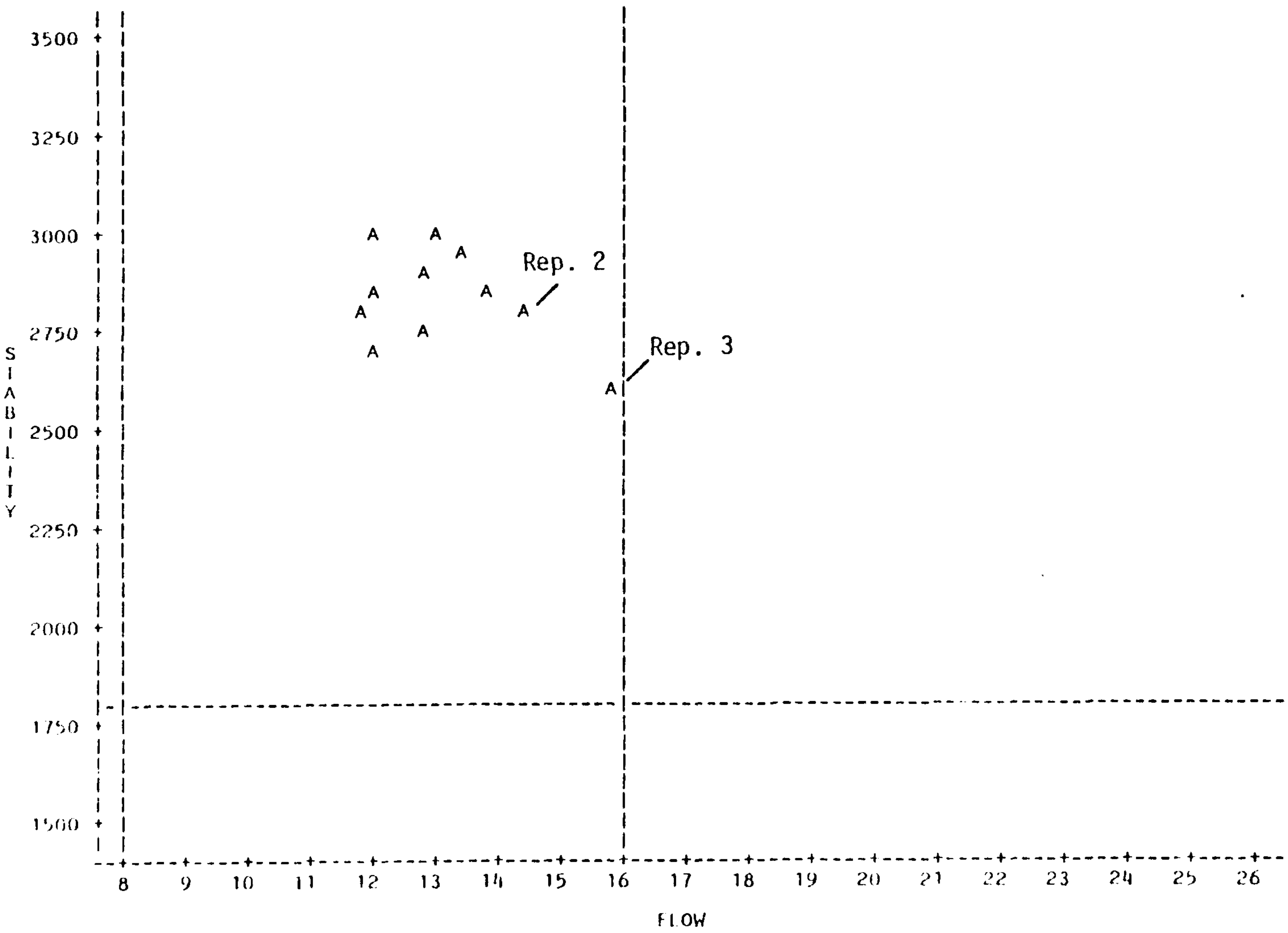
STABILITY VS. FLOW
GRADATIO=FAAM   ASPHALT CONTENT=7

LEGEND: A = 1 OBS, B = 2 OBS, ETC.



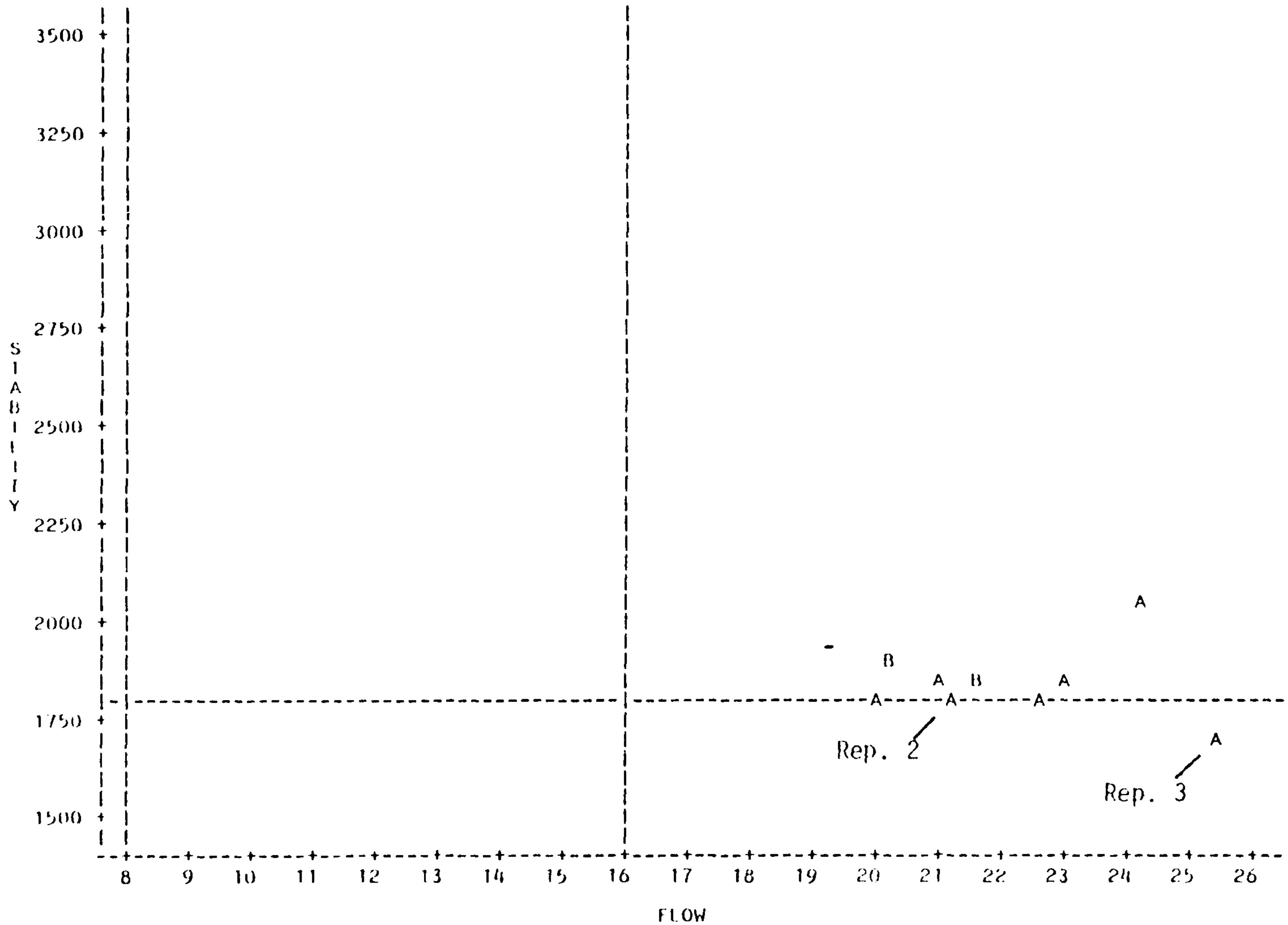
STABILITY VS. FLOW
GRADATIO=FAAU ASPHALT CONTENT=6

LEGEND: A = 1 OBS, B = 2 OBS, ETC.



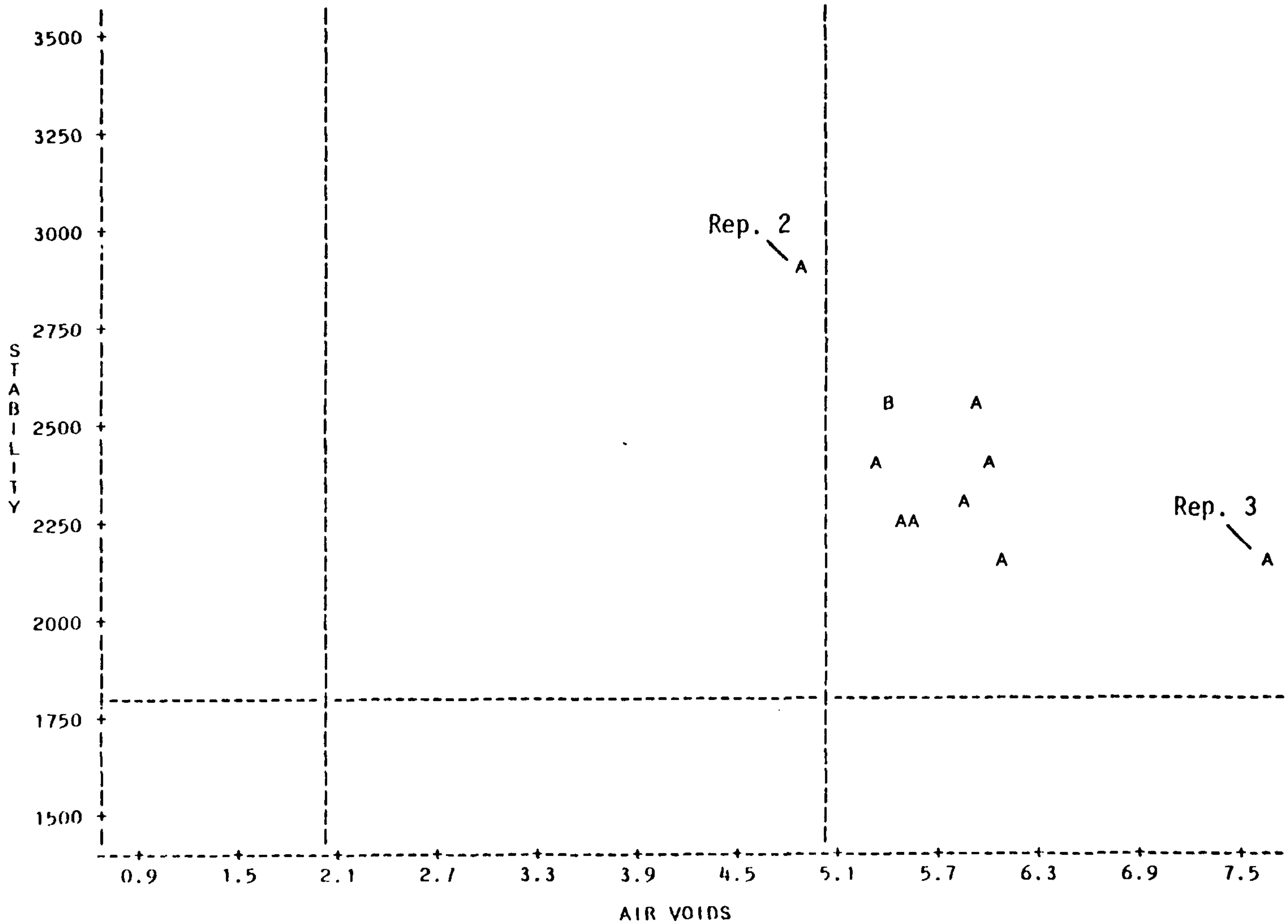
STABILITY VS. FLOW
GRADATIO=FAAU   ASPHALT CONTENT=7.5

LEGEND: A = 1 OBS, B = 2 OBS, ETC.



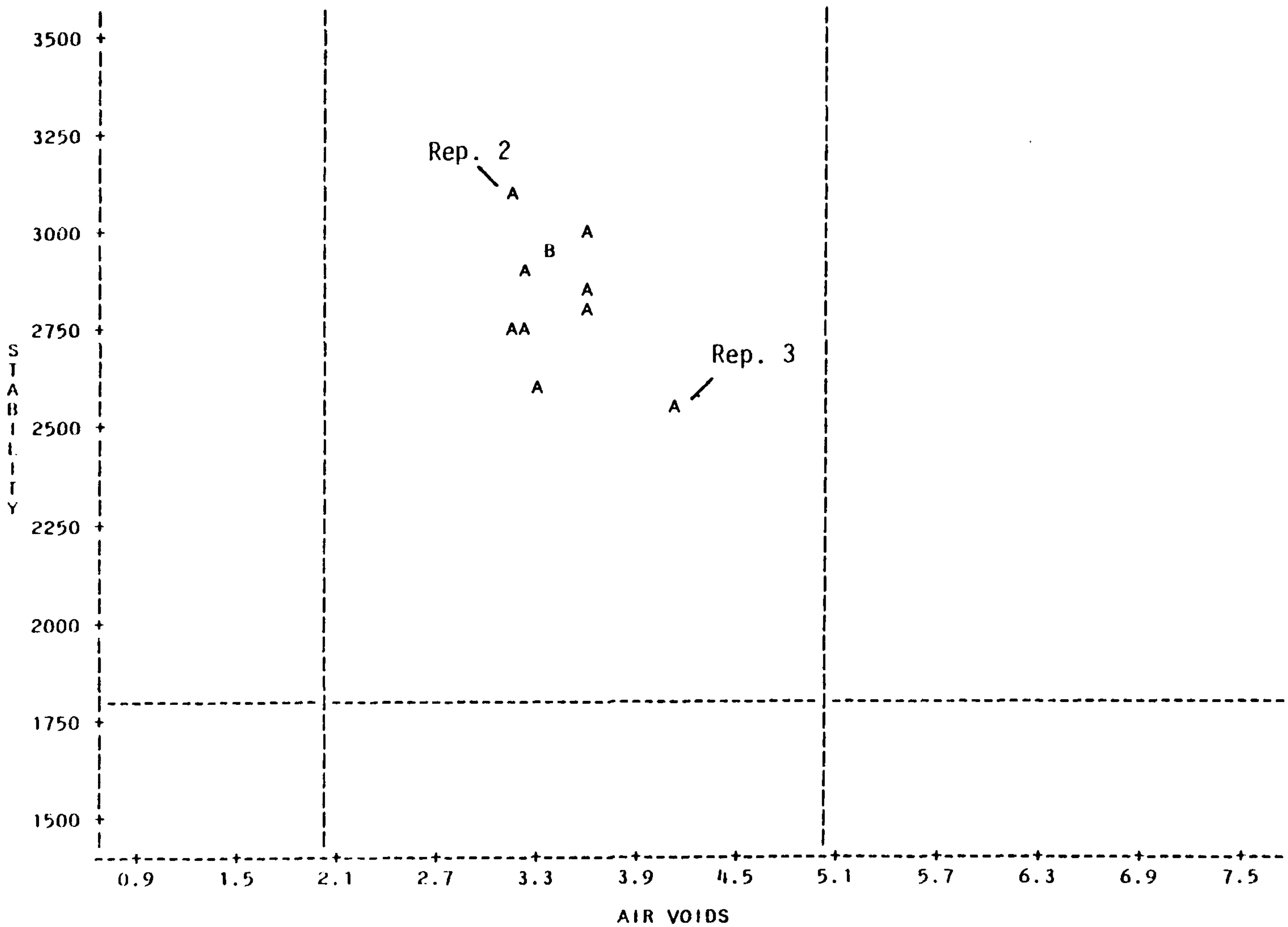
STABILITY VS. AIR VOIDS
GRADATIO=FAAL ASPHALT CONTENT=5

LEGEND: A = 1 OBS, B = 2 OBS, ETC.



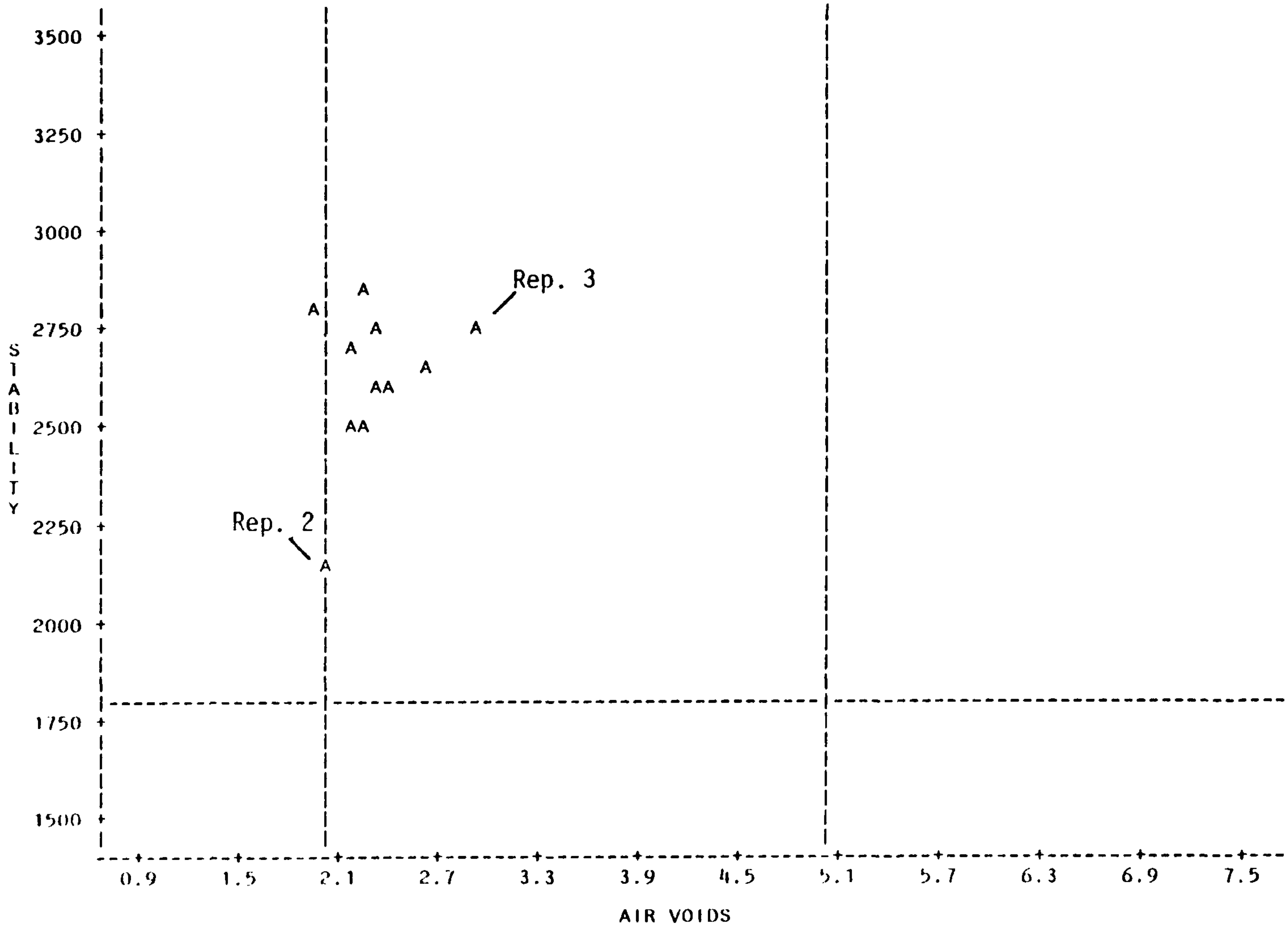
STABILITY VS. AIR VOIDS
GRADATIO=FAAM   ASPHALT CONTENT=5.5

LEGEND: A = 1 OBS, B = 2 OBS, ETC.



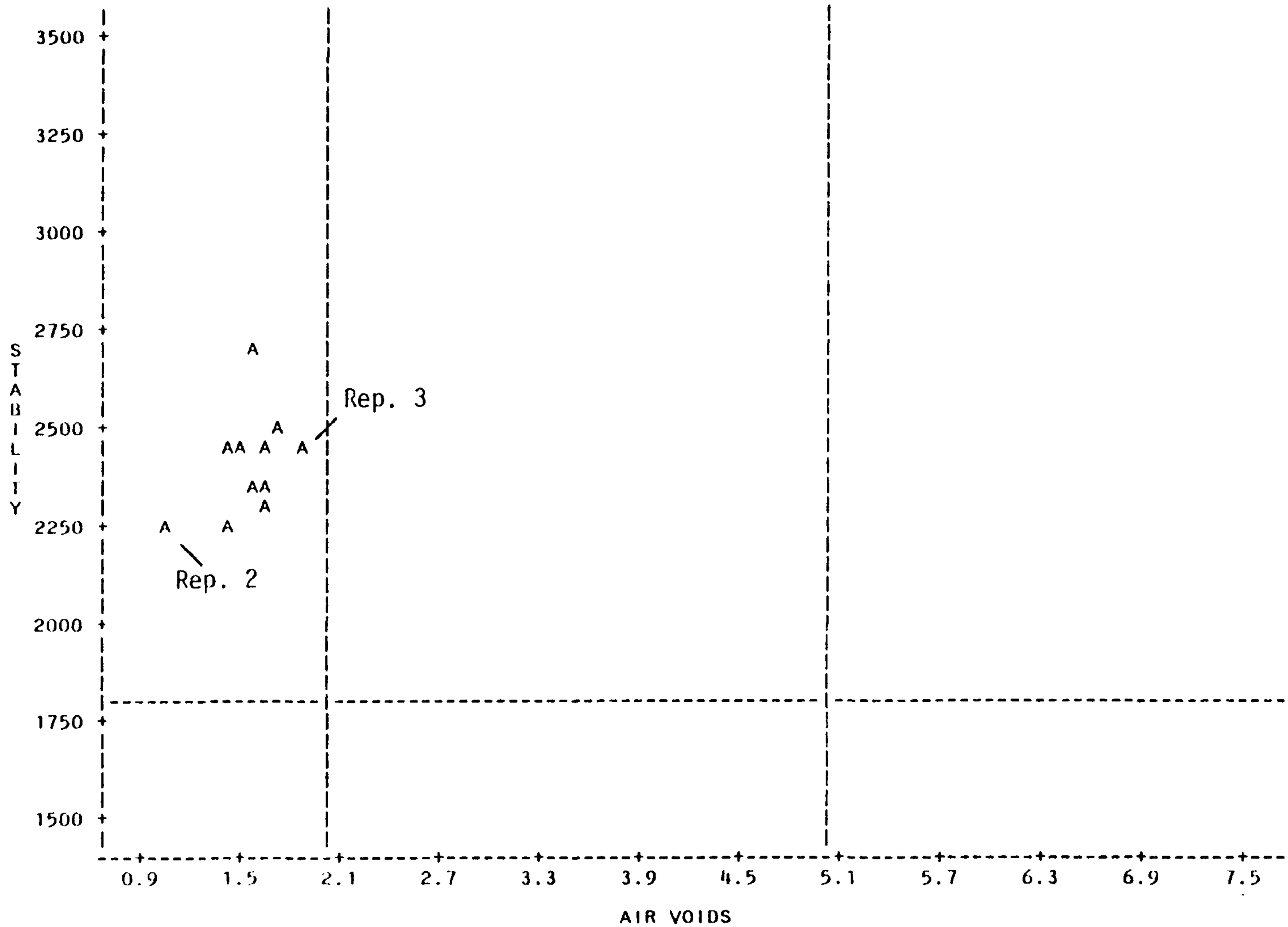
STABILITY VS. AIR VOIDS
GRADATIO=FAAM ASPHALT CONTENT=6

LEGEND: A = 1 OBS, B = 2 OBS, ETC.



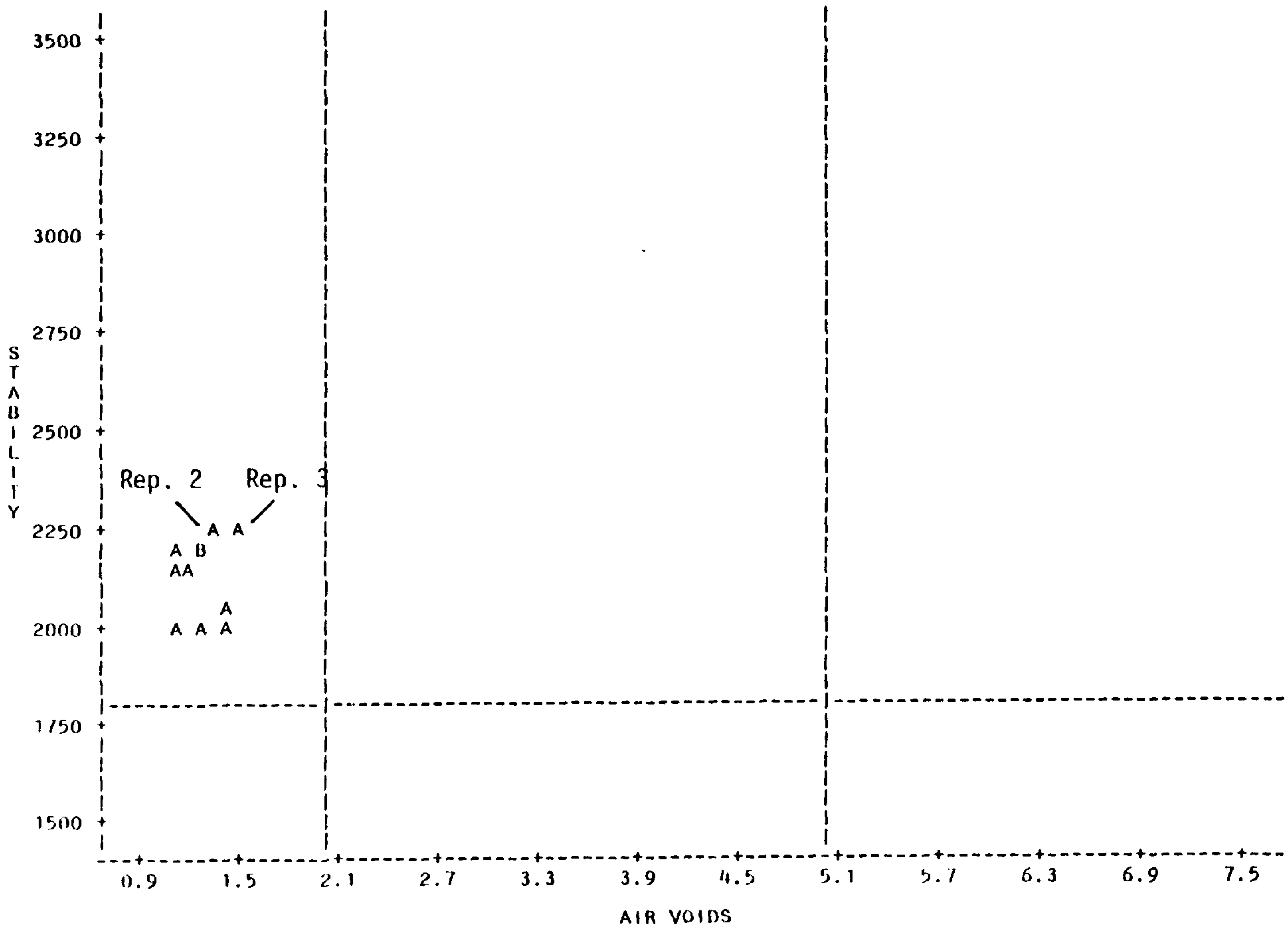
STABILITY VS. AIR VOIDS
GRADATIO=FAAM   ASPHALT CONTENT=6.5

LEGEND: A = 1 OBS, B = 2 OBS, ETC.



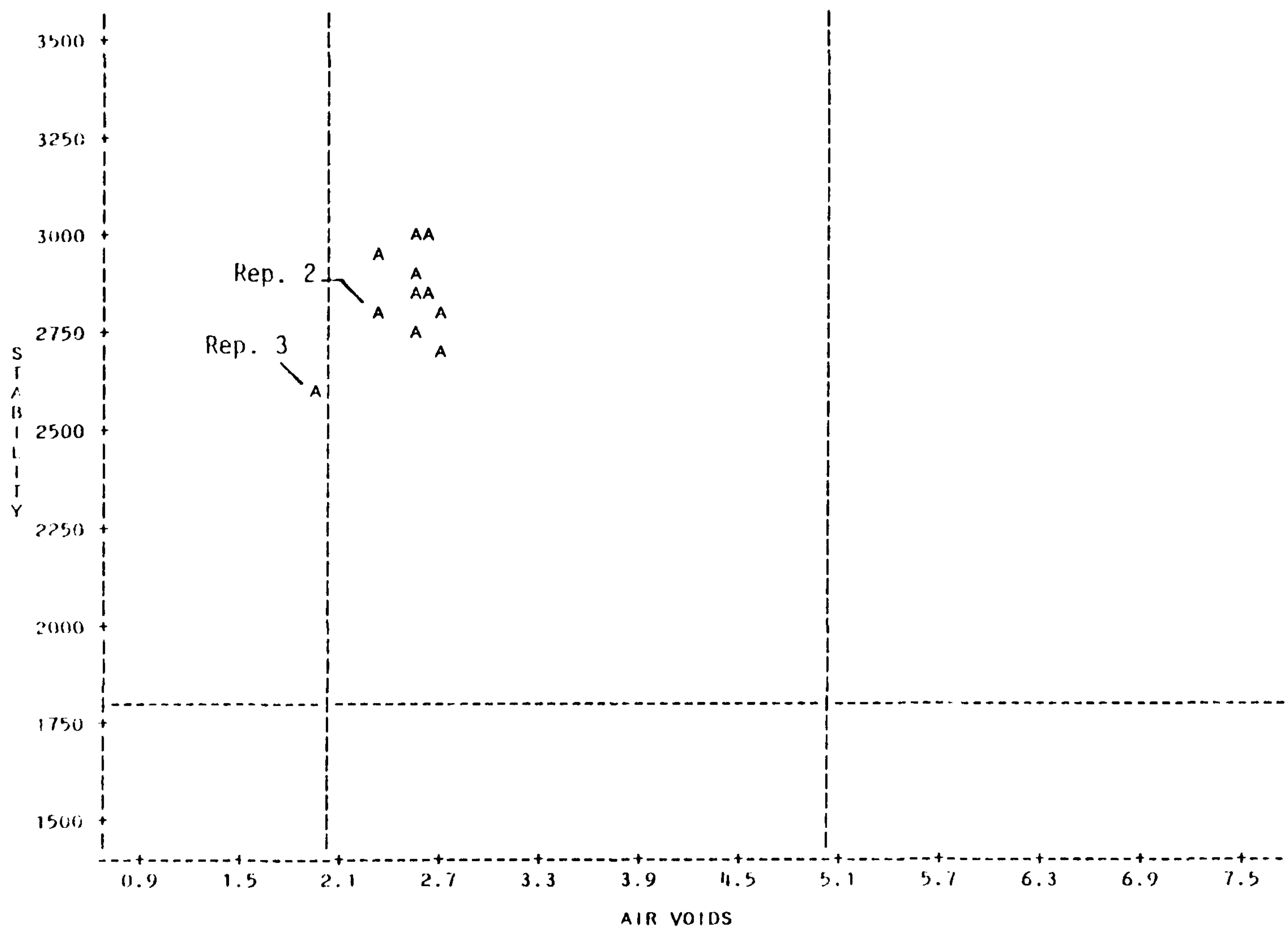
STABILITY VS. AIR VOIDS
GRADATIO=FAAM ASPHALT CONTENT=7

LEGEND: A = 1 OBS, B = 2 OBS, ETC.



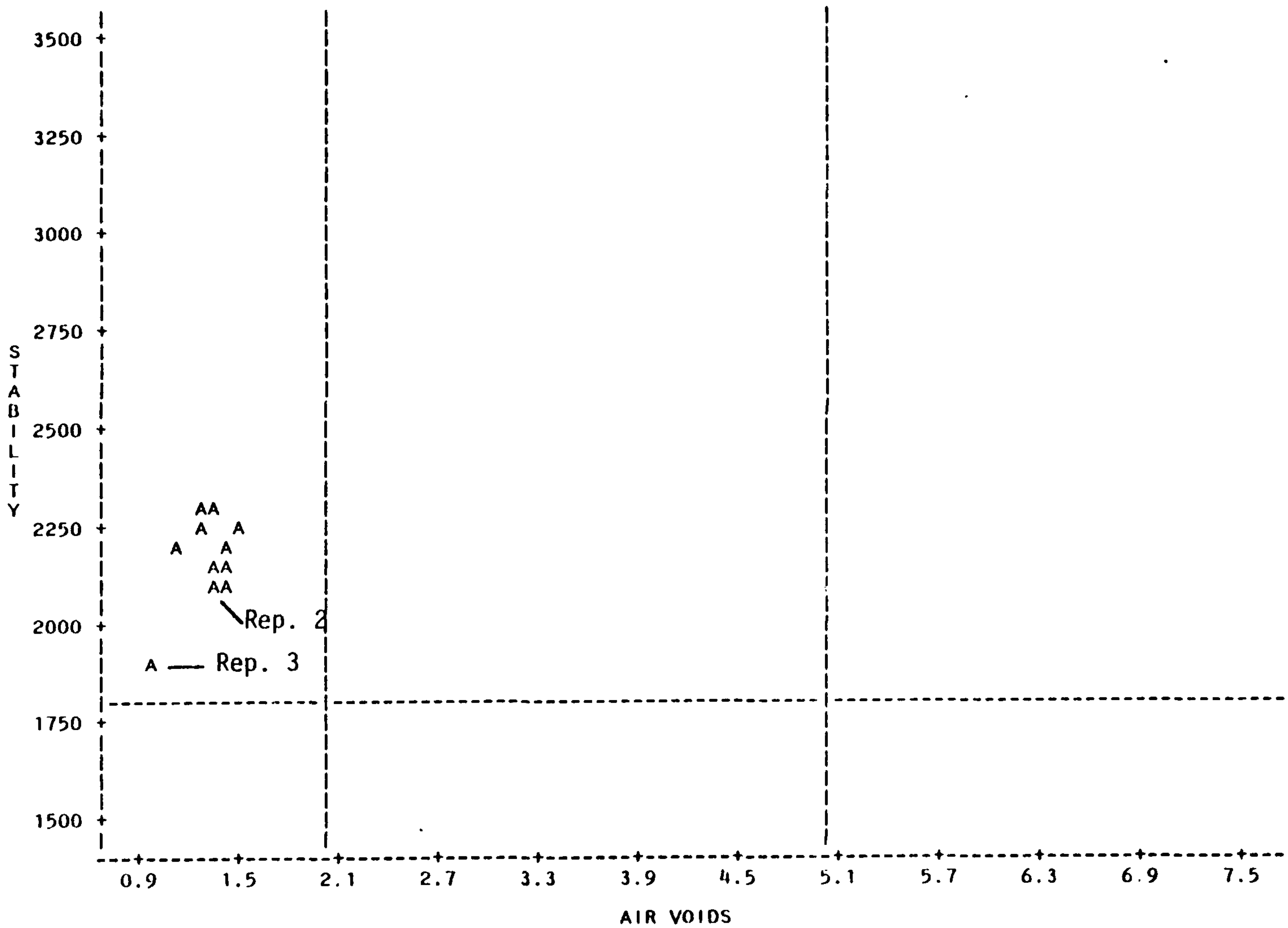
STABILITY VS. AIR VOIDS
GRADATIO=FAAU ASPHALT CONTENT=6

LEGEND: A = 1 OBS, B = 2 OBS, ETC.



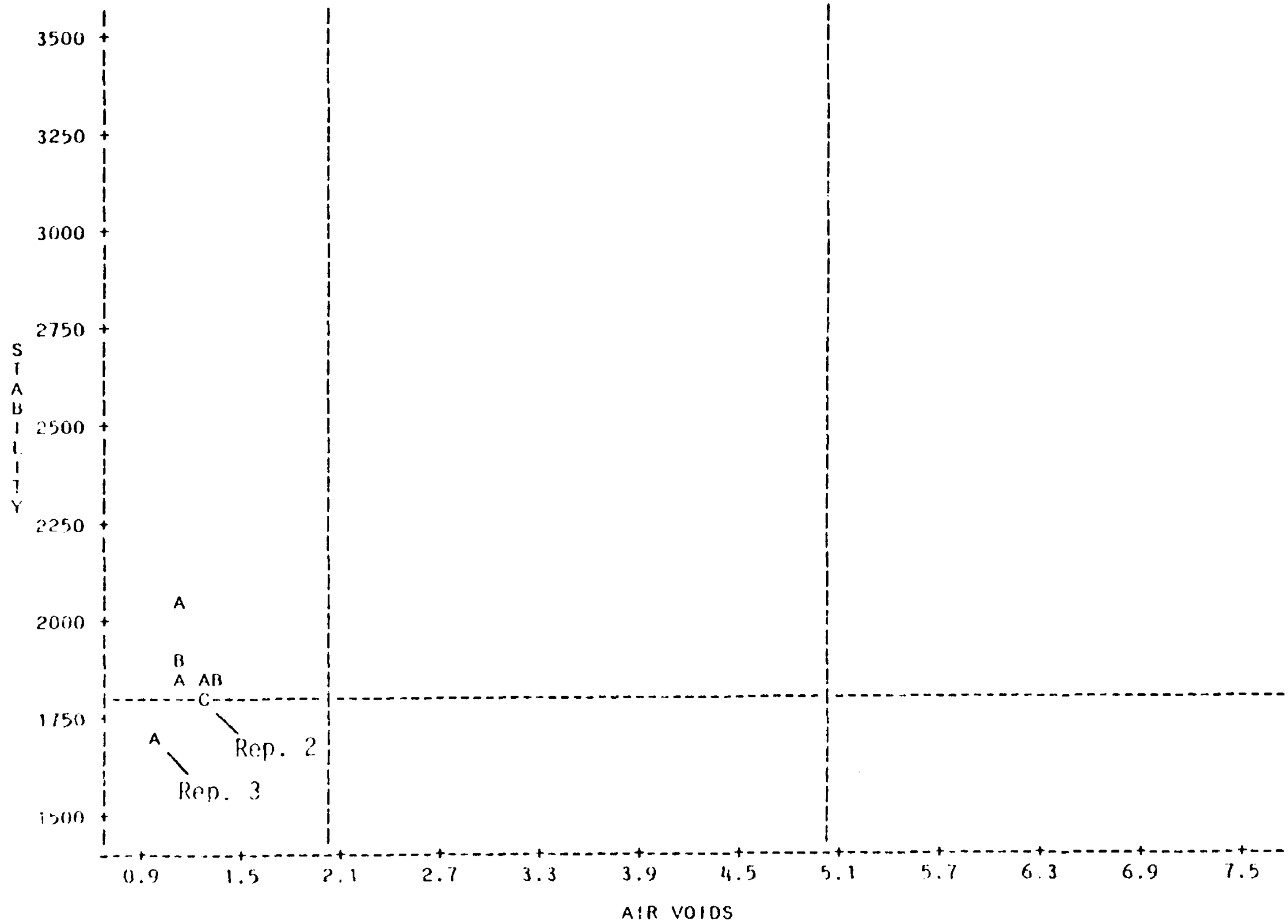
STABILITY VS. AIR VOIDS
GRADATIO=FAAU   ASPHALT CONTENT=7

LEGEND: A = 1 OBS, B = 2 OBS, ETC.



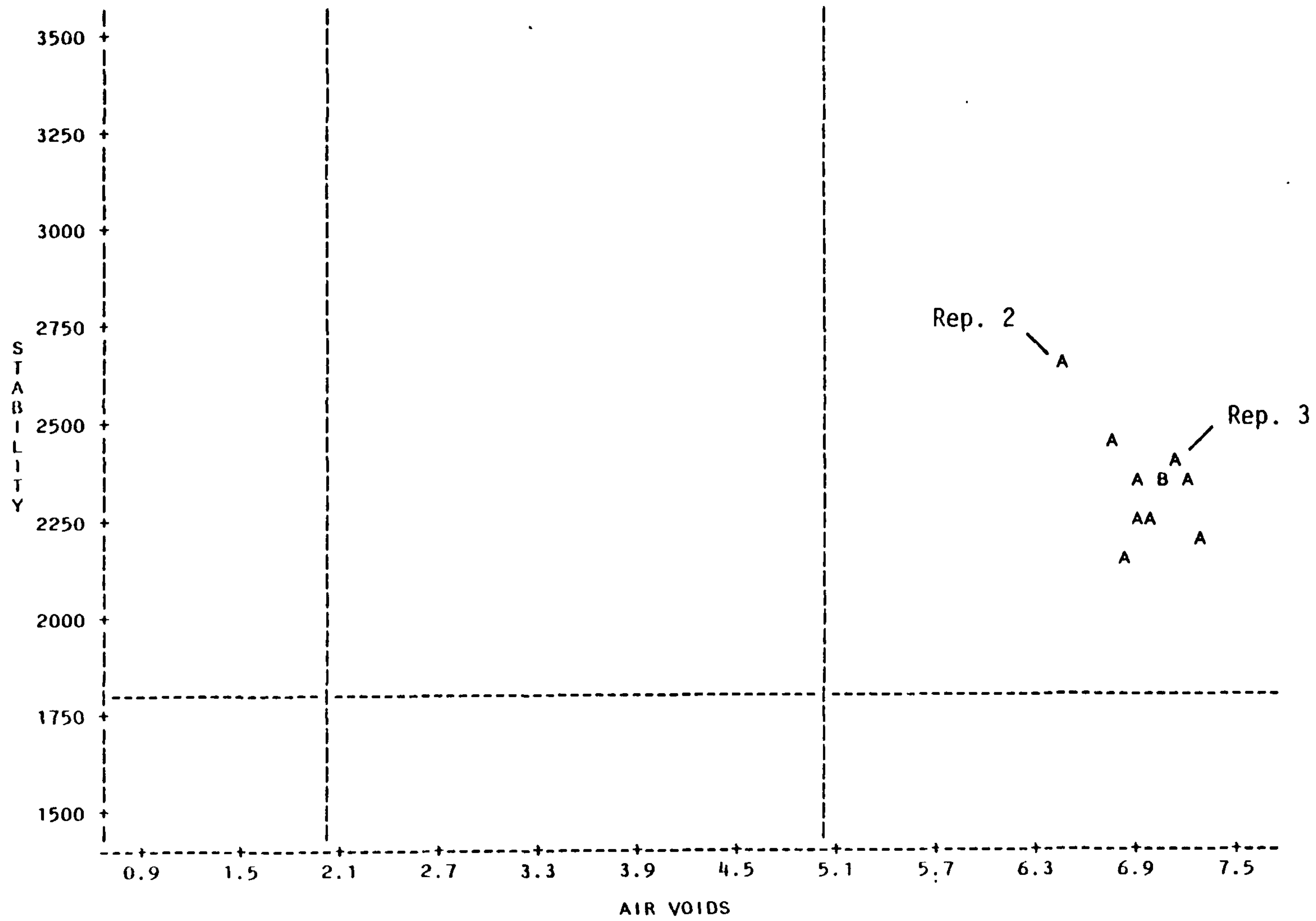
STABILITY VS. AIR VOIDS
GRADATIO=FAAU   ASPHALT CONTENT=7.5

LEGEND: A = 1 OBS, B = 2 OBS, ETC.



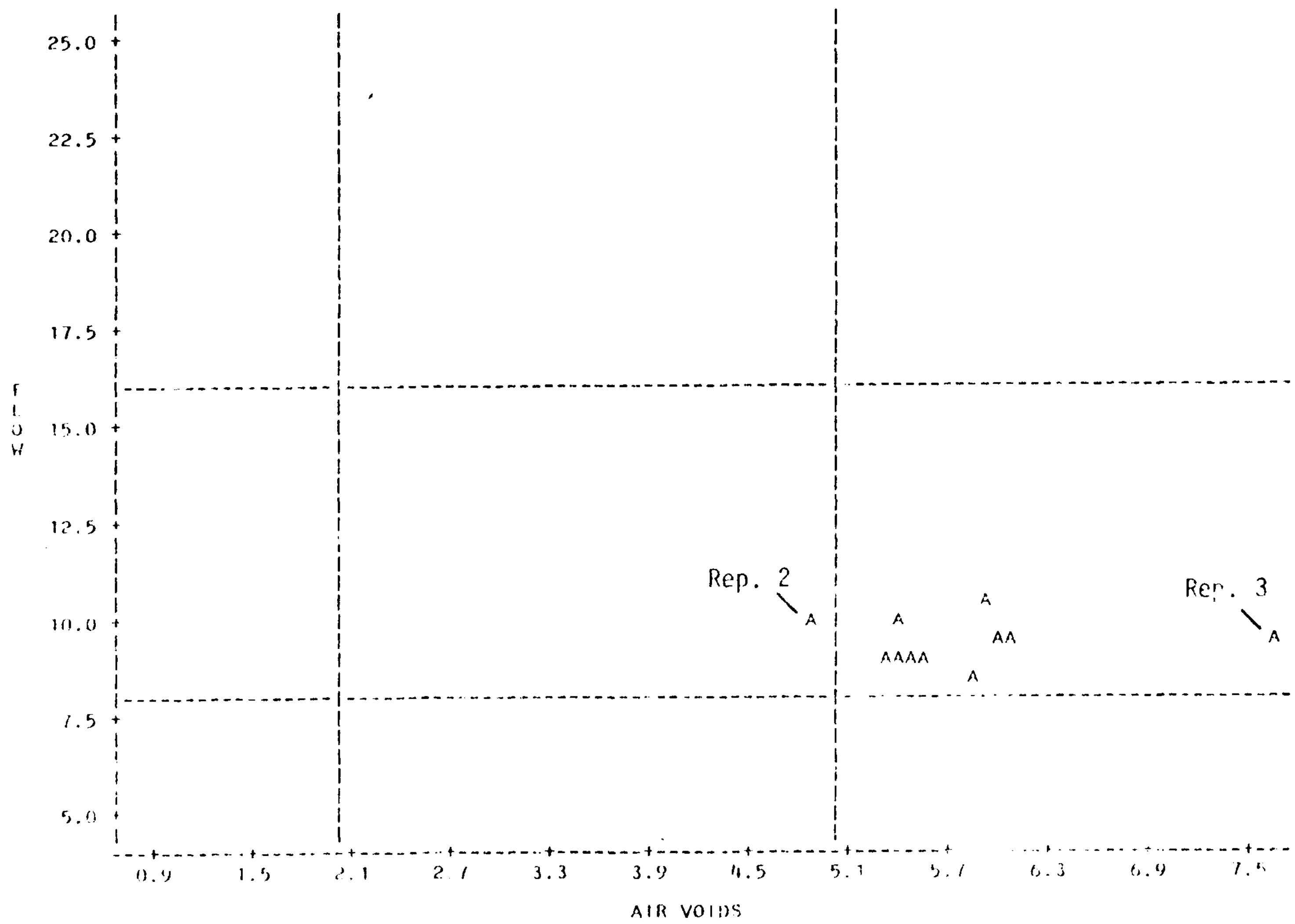
STABILITY VS. AIR VOIDS
GRADATIO=JMF   ASPHALT CONTENT=5

LEGEND: A = 1 OBS, B = 2 OBS, ETC.



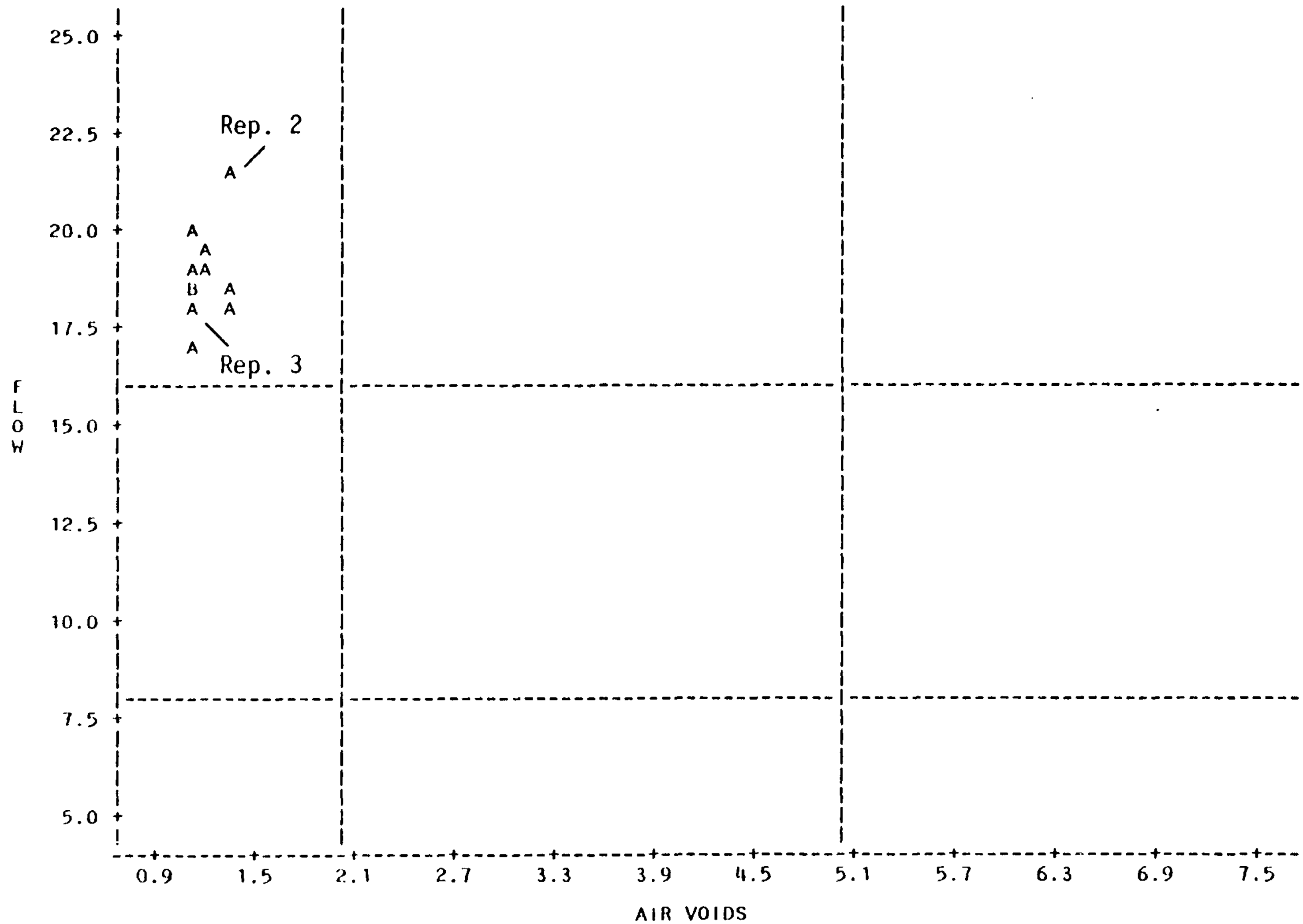
FLOW VS. AIR VOIDS
GRADATIO=FAAL ASPHALT CONTENT=5

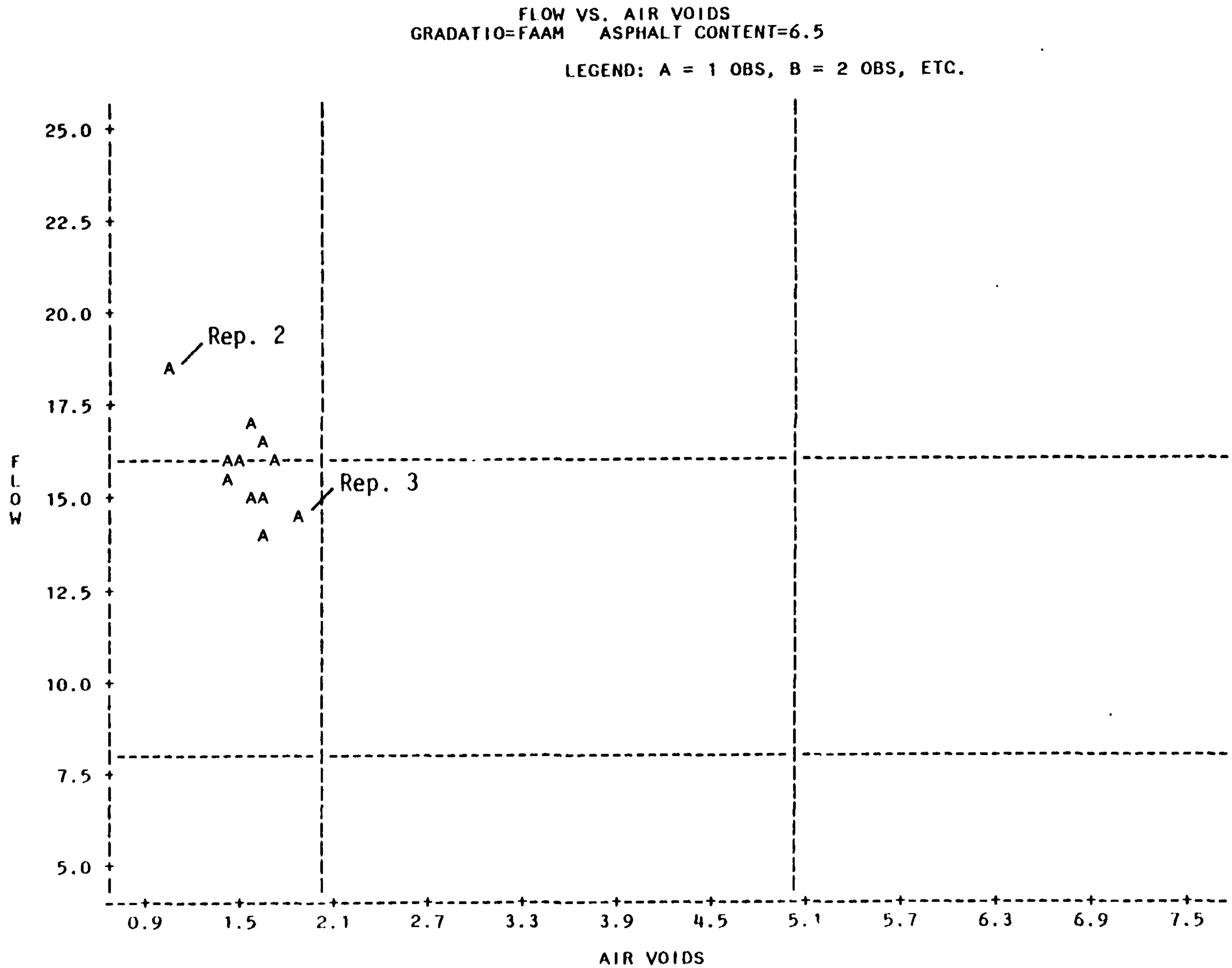
LEGEND: A = 1 OBS, B = 2 OBS, ETC.



FLOW VS. AIR VOIDS
GRADATIO=FAAL ASPHALT CONTENT=7.5

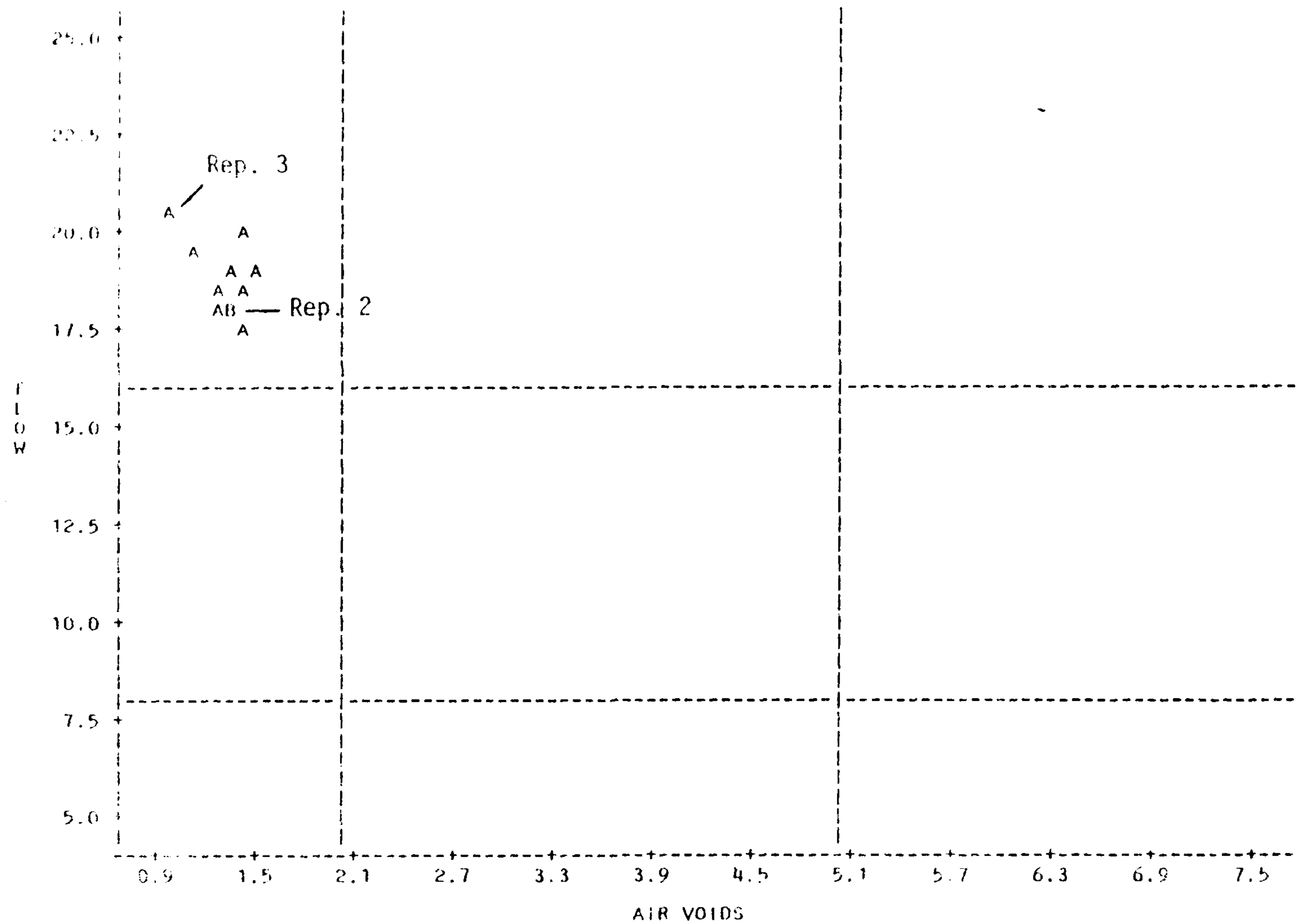
LEGEND: A = 1 OBS, B = 2 OBS, ETC.




FLOW VS. AIR VOIDS
GRADATIO=FAAM ASPHALT CONTENT=6.5
LEGEND: A = 1 OBS, B = 2 OBS, ETC.
FLOW
25.0
22.5
20.0
17.5
15.0
12.5
10.0
7.5
5.0
Rep. 2
Rep. 3
0.9
1.5
2.1
2.7
3.3
3.9
4.5
5.1
5.7
6.3
6.9
7.5
AIR VOIDS

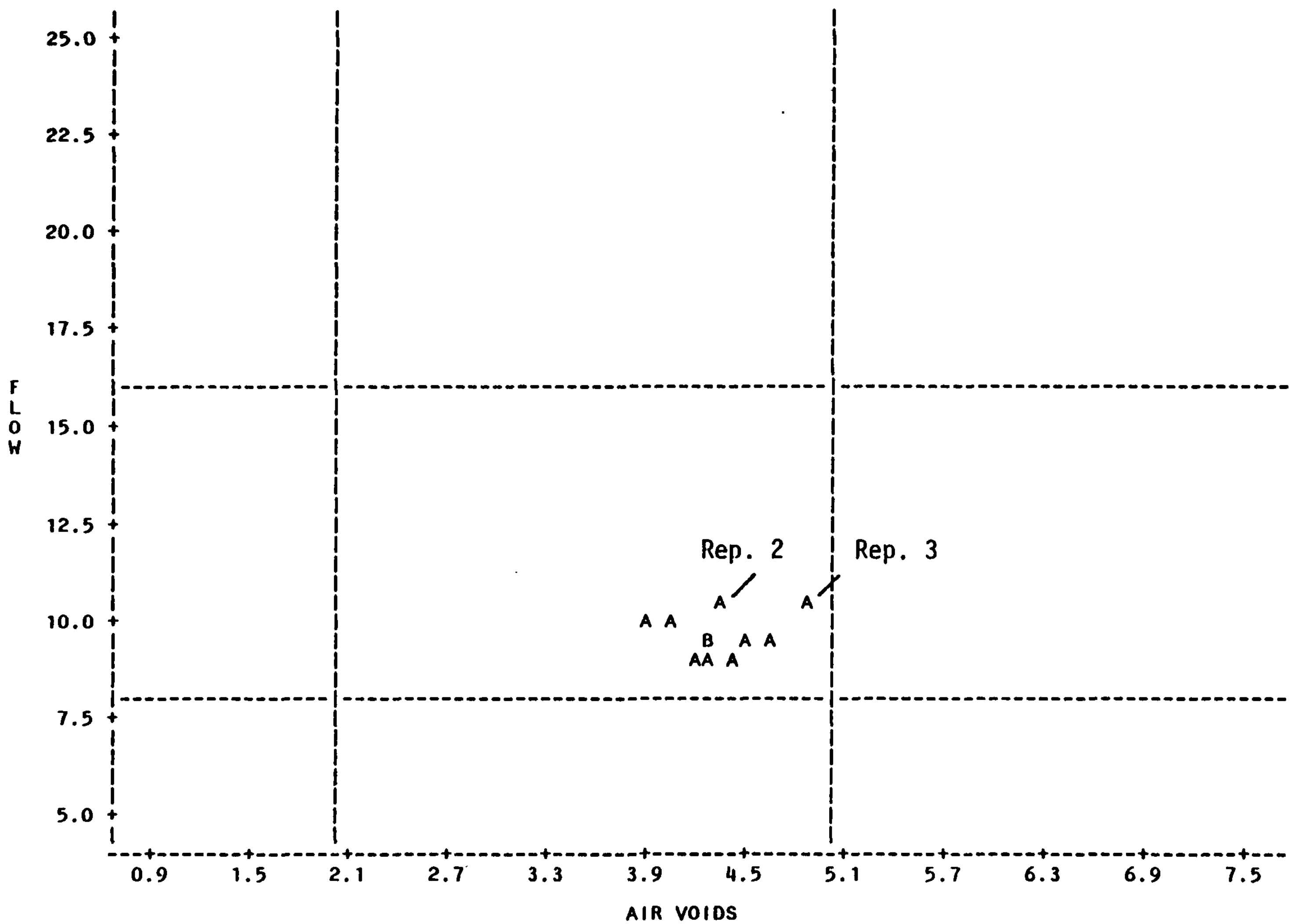
FLOW VS. AIR VOIDS
GRADATIO=FAAU ASPHALT CONTENT=7

LEGEND: A = 1 OBS, B = 2 OBS, ETC.



FLOW VS. AIR VOIDS
GRADATIO=JMF   ASPHALT CONTENT=6

LEGEND: A = 1 OBS, B = 2 OBS, ETC.



Appendix D

Temperatures Recorded During Marshall Briquet Mixing Process in the Laboratory

Gradation	Replicate	Asphalt Content	Temperature		
			Asphalt	Mixing	Compaction
FAAL	1	5.0	304	307	250
		5.5	305	307	250
		6.0	305	307	250
		6.5	304	307	250
		7.0	307	298	250
		7.5	307	301	250
FAAL	2	5.0	307	307	250
		5.5	307	292	250
		6.0	301	305	250
		6.5	301	300	250
		7.0	304	301	250
		7.5	307	300	250
FAAL	3	5.0	303	302	250
		5.5	297	307	250
		6.0	306	307	250
		6.5	300	307	250
		7.0	300	306	250
		7.5	302	297	250
FAAL	4	5.0	302	307	250
		5.5	300	307	250
		6.0	305	307	250
		6.5	300	300	250
		7.0	307	307	250
		7.5	307	307	250
FAAL	5	5.0	305	301	250
		5.5	301	302	250
		6.0	299	307	250
		6.5	300	307	250
		7.0	297	305	250
		7.5	305	301	250
FAAL	6	5.0	298	307	250
		5.5	302	301	250

		6.0	300	305	250
		6.5	307	307	250
		7.0	300	300	250
		7.5	298	307	250
FAAL	7	5.0	302	304	250
		5.5	305	300	250
		6.0	298	302	250
		6.5	297	307	250
		7.0	297	307	250
		7.5	300	306	250
FAAL	8	5.0	307	299	250
		5.5	297	307	250
		6.0	300	303	250
		6.5	297	301	250
		7.0	307	305	250
		7.5	302	304	250
FAAL	9	5.0	303	306	250
		5.5	307	304	250
		6.0	302	304	250
		6.5	305	301	250
		7.0	300	300	250
		7.5	303	302	250
FAAL	10	5.0	303	302	250
		5.5	301	304	250
		6.0	307	307	250
		6.5	305	306	250
		7.0	297	307	250
		7.5	299	300	250
FAAL	11	5.0	297	305	250
		5.5	300	298	250
		6.0	297	305	250
		6.5	300	307	250
		7.0	300	301	250
		7.5	297	302	250
FAAL	12	5.0	306	307	250
		5.5	305	305	250
		6.0	307	304	250
		6.5	307	305	250
		7.0	301	299	245
		7.5	307	306	250
FAAM	1	5.0	306	306	250
		5.5	307	307	250
		6.0	304	305	250
		6.5	303	307	250
		7.0	297	303	250
		7.5	307	301	250

FAAM	2	5.0	302	299	250
		5.5	306	297	250
		6.0	300	300	250
		6.5	298	307	250
		7.0	301	305	250
		7.5	304	306	250
FAAM	3	5.0	302	302	250
		5.5	303	302	250
		6.0	297	305	250
		6.5	300	307	250
		7.0	307	307	250
		7.5	301	305	250
FAAM	4	5.0	307	307	250
		5.5	307	303	250
		6.0	307	307	250
		6.5	299	305	250
		7.0	305	305	250
		7.5	298	306	250
FAAM	5	5.0	300	305	250
		5.5	303	299	250
		6.0	300	307	250
		6.5	307	307	250
		7.0	299	307	250
		7.5	307	300	245
FAAM	6	5.0	301	301	250
		5.5	301	307	250
		6.0	305	307	250
		6.5	299	307	250
		7.0	297	307	250
		7.5	307	307	245
FAAM	7	5.0	303	300	250
		5.5	307	302	250
		6.0	295	307	250
		6.5	307	305	250
		7.0	307	306	250
		7.5	302	307	250
FAAM	8	5.0	307	307	250
		5.5	300	305	250
		6.0	302	307	250
		6.5	297	306	250
		7.0	297	302	250
		7.5	300	305	250
FAAM	9	5.0	302	301	250
		5.5	307	303	250
		6.0	299	305	250
		6.5	305	301	250
		7.0	299	307	250

		7.5	300	307	250
FAAM	10	5.0	297	301	250
		5.5	299	300	250
		6.0	307	301	250
		6.5	297	307	250
		7.0	307	307	250
		7.5	297	305	250
FAAM	11	5.0	307	305	250
		5.5	307	302	250
		6.0	303	304	250
		6.5	304	301	250
		7.0	297	300	250
		7.5	307	299	250
FAAM	12	5.0	297	301	250
		5.5	297	298	250
		6.0	301	298	250
		6.5	299	297	250
		7.0	297	307	250
		7.5	301	300	250
FAAU	1	5.0	304	305	250
		5.5	297	307	250
		6.0	300	303	250
		6.5	307	301	250
		7.0	300	298	250
		7.5	300	307	250
FAAU	2	5.0	307	307	250
		5.5	307	292	245
		6.0	305	299	250
		6.5	305	301	250
		7.0	303	304	250
		7.5	300	299	250
FAAU	3	5.0	300	305	250
		5.5	307	307	250
		6.0	305	297	250
		6.5	300	307	245
		7.0	305	300	250
		7.5	304	304	250
FAAU	4	5.0	307	305	245
		5.5	307	307	250
		6.0	299	305	250
		6.5	307	304	250
		7.0	307	305	250
		7.5	298	306	250
FAAU	5	5.0	307	307	250
		5.5	307	302	250
		6.0	307	304	250

		6.5	305	307	250
		7.0	306	307	250
		7.5	305	304	250
FAAU	6	5.0	305	302	250
		5.5	306	307	250
		6.0	297	307	250
		6.5	300	307	250
		7.0	300	301	250
		7.5	300	301	250
FAAU	7	5.0	305	307	250
		5.5	297	302	250
		6.0	307	305	250
		6.5	297	307	250
		7.0	307	306	250
		7.5	297	300	250
FAAU	8	5.0	300	304	250
		5.5	297	307	250
		6.0	300	305	250
		6.5	301	307	250
		7.0	299	301	250
		7.5	307	305	250
FAAU	9	5.0	305	307	250
		5.5	307	303	250
		6.0	305	306	250
		6.5	301	307	250
		7.0	305	304	250
		7.5	301	307	250
FAAU	10	5.0	307	302	250
		5.5	304	303	250
		6.0	298	305	250
		6.5	298	307	250
		7.0	299	307	250
		7.5	300	307	250
FAAU	11	5.0	307	303	250
		5.5	307	307	250
		6.0	300	301	250
		6.5	301	300	250
		7.0	300	307	250
		7.5	298	304	250
FAAU	12	5.0	305	307	250
		5.5	298	304	250
		6.0	297	307	250
		6.5	297	299	250
		7.0	305	305	250
		7.5	307	301	250
JMF	1	5.0	300	307	250

		5.5	300	307	250
		6.0	301	297	250
		6.5	302	307	250
		7.0	307	301	250
		7.5	305	302	250
JMF	2	5.0	303	304	250
		5.5	304	305	250
		6.0	299	301	250
		6.5	306	307	250
		7.0	305	300	250
		7.5	304	307	250
JMF	3	5.0	307	304	250
		5.5	307	307	245
		6.0	304	307	250
		6.5	305	305	250
		7.0	297	301	250
		7.5	307	306	250
JMF	4	5.0	300	305	250
		5.5	299	307	250
		6.0	304	307	250
		6.5	298	307	250
		7.0	307	302	250
		7.5	303	305	250
JMF	5	5.0	307	295	245
		5.5	297	307	250
		6.0	300	307	250
		6.5	307	307	250
		7.0	307	304	250
		7.5	300	307	250
JMF	6	5.0	297	307	250
		5.5	300	307	250
		6.0	302	303	250
		6.5	305	306	250
		7.0	298	306	250
		7.5	298	305	250
JMF	7	5.0	303	301	250
		5.5	305	307	250
		6.0	301	307	250
		6.5	306	302	250
		7.0	298	301	250
		7.5	307	304	250
JMF	8	5.0	307	304	250
		5.5	306	307	250
		6.0	307	306	250
		6.5	305	307	250
		7.0	307	307	250
		7.5	307	305	250

JMF	9	5.0	307	307	250
		5.5	305	307	250
		6.0	297	307	250
		6.5	301	307	250
		7.0	307	302	250
		7.5	298	307	250
JMF	10	5.0	307	300	250
		5.5	305	304	250
		6.0	307	307	250
		6.5	306	307	250
		7.0	300	307	250
		7.5	307	307	250
JMF	11	5.0	300	301	250
		5.5	302	305	250
		6.0	307	307	250
		6.5	307	307	250
		7.0	300	302	250
		7.5	298	307	250
JMF	12	5.0	302	299	250
		5.5	299	307	250
		6.0	307	305	250
		6.5	307	304	250
		7.0	306	303	250
		7.5	300	304	250

Appendix E

Summary of Marshall Stability Results

Gradation	Asphalt Content (%)	Mean (lbs)	Standard Deviation (lbs)	Coef. of Vari. * (%)	Min. Value (lbs)	Max. Value (lbs)	Range (lbs)
FAA Upper	5.0	3036	160	5.3	2800	3360	560
	5.5	2987	130	4.3	2770	3160	390
	6.0	2836	128	4.5	2600	3010	410
	6.5	2517	90	3.6	2360	2670	310
	7.0	2165	115	5.3	1880	2280	400
	7.5	1848	88	4.7	1699	2045	346
FAA Midpoint	5.0	2805	78	2.8	2720	3000	280
	5.5	2835	168	5.9	2540	3090	550
	6.0	2620	199	7.6	2140	2860	720
	6.5	2406	132	5.5	2230	2700	470
	7.0	2136	97	4.5	1990	2240	250
	7.5	1773	132	7.4	1500	1940	440
FAA Lower	5.0	2405	224	9.3	2130	2890	760
	5.5	2523	137	5.4	2270	2680	410
	6.0	2505	160	6.4	2290	2810	520
	6.5	2424	213	8.8	2100	2700	600
	7.0	2201	139	6.3	2040	2430	390
	7.5	1905	133	7.0	1730	2120	390
JMF	5.0	2345	140	6.0	2150	2670	520
	5.5	2420	173	7.1	2141	2780	639
	6.0	2450	167	6.8	2170	2670	500
	6.5	2513	132	5.2	2340	2730	390
	7.0	2360	108	4.6	2179	2550	371
	7.5	2119	53	2.5	2035	2200	165

* Values for Coefficient of Variation are based on Mean and Standard Deviation Values before rounding for inclusion in Appendix.

Appendix F

Summary of Marshall Flow Results

Gradation	Asphalt Content (%)	Mean (1/100")	Standard Deviation (1/100")	Coef. of Vari. * (%)	Min. Value (1/100")	Max. Value (1/100")	Range (1/100")
FAA Upper	5.0	9.7	0.42	4.3	8.9	10.5	1.6
	5.5	10.4	0.98	9.4	9.2	12.3	3.1
	6.0	13.0	1.22	9.3	11.8	15.8	4.0
	6.5	15.7	1.05	6.7	14.5	18.2	3.7
	7.0	18.8	0.89	4.7	17.6	20.5	2.9
	7.5	21.9	1.73	7.9	20.0	25.5	5.5
FAA Midpoint	5.0	9.5	0.56	5.9	8.7	10.4	1.7
	5.5	11.1	0.54	4.8	10.5	12.1	1.6
	6.0	12.9	1.10	8.5	12.0	15.6	3.6
	6.5	15.8	1.24	7.8	14.1	18.5	4.4
	7.0	18.5	1.02	5.5	16.8	19.8	3.0
	7.5	21.9	1.39	6.3	20.0	24.1	4.1
FAA Lower	5.0	9.4	0.55	5.9	8.6	10.3	1.7
	5.5	10.1	0.75	7.5	9.2	11.9	2.7
	6.0	11.4	0.71	6.2	10.4	12.5	2.1
	6.5	13.6	1.16	8.6	12.1	15.9	3.8
	7.0	15.8	0.98	6.2	14.3	17.5	3.2
	7.5	18.9	1.18	6.3	17.0	21.4	4.4
JMF	5.0	8.8	0.43	4.9	8.3	9.6	1.3
	5.5	9.1	0.54	6.0	8.0	9.7	1.7
	6.0	9.6	0.52	5.4	8.8	10.5	1.7
	6.5	10.9	0.50	4.6	10.0	11.7	1.7
	7.0	13.4	0.60	4.5	12.3	14.1	1.8
	7.5	16.5	0.79	4.8	15.1	17.9	2.8

* Values for Coefficient of Variation are based on Mean and Standard Deviation Values before rounding for inclusion in Appendix.

Appendix G

Summary of Air Voids Results

Gradation	Asphalt Content (%)	Mean (%)	Standard Deviation (%)	Coef. of Vari. * (%)	Min. Value (%)	Max. Value (%)	Range (%)
FAA Upper	5.0	5.3	0.34	6.4	4.81	5.85	1.04
	5.5	3.7	0.29	7.9	3.12	4.23	1.11
	6.0	2.5	0.21	8.3	1.98	2.69	0.71
	6.5	1.7	0.13	7.3	1.52	1.98	0.46
	7.0	1.3	0.15	11.7	0.97	1.50	0.53
	7.5	1.2	0.12	9.6	0.97	1.37	0.40
FAA Midpoint	5.0	5.0	0.31	6.3	4.53	5.42	0.89
	5.5	3.4	0.28	8.3	3.16	4.12	0.96
	6.0	2.3	0.27	11.6	1.97	2.91	0.94
	6.5	1.5	0.20	12.9	1.08	1.85	0.77
	7.0	1.3	0.12	9.5	1.12	1.48	0.36
	7.5	1.1	0.09	8.3	0.95	1.34	0.39
FAA Lower	5.0	5.8	0.71	12.4	4.89	7.64	2.75
	5.5	4.1	0.26	6.3	3.60	4.57	0.97
	6.0	2.8	0.31	11.4	2.23	3.33	1.10
	6.5	1.9	0.20	10.5	1.63	2.19	0.56
	7.0	1.4	0.08	6.2	1.26	1.52	0.26
	7.5	1.2	0.11	9.0	1.10	1.39	0.29
JMF	5.0	6.9	0.22	3.2	6.48	7.29	0.81
	5.5	5.6	0.34	6.0	5.07	6.16	1.09
	6.0	4.3	0.27	6.1	3.91	4.85	0.94
	6.5	3.1	0.25	8.1	2.55	3.37	0.82
	7.0	2.0	0.17	8.4	1.83	2.31	0.48
	7.5	1.6	0.10	6.6	1.42	1.76	0.34

* Values for Coefficient of Variation are based on Mean and Standard Deviation Values before rounding for inclusion in Appendix.

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